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Westinghouse
Motor Generators
and
Frequency Changers

Instruction Book 5176-A

IMPORTANT

Keep the generator and motor clean. The finest machines and the most expensive plant may be shut down by accident if they do not have protection and care. The insulation must be kept clean and dry. Oil and dirt in the insulation are as much out of place as grit or sand in a cylinder or bearing.

Before installing or operating a machine, read all of the following instructions carefully, making note of the parts and points to be observed. On account of divergence in construction of the different types, it has been impracticable to arrange all information on any one line of machines in consecutive order.

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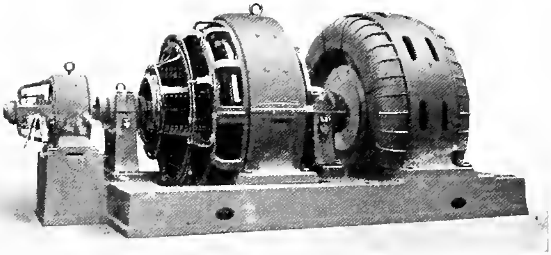
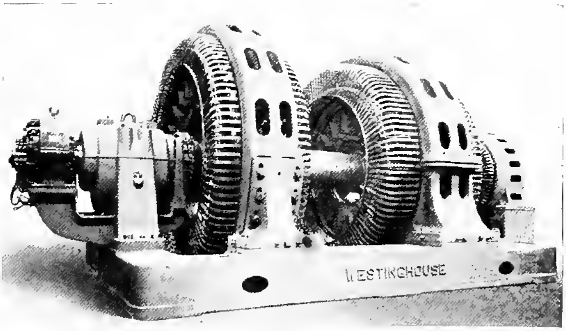


1500-Kw., 600-Volt, 2160-H.P. Motor, 2300-Volts, 3-Phase, 60-Cycle, 600-R.P.M. Motor Generator



6835 Kva. Frequency Changer. 25-Cycles, 13,000-Volts, 3-Phase Motor, 62½-Cycles, 4000-Volt, 3-Phase Generator

FOREWORD

This instruction book covers the larger Westinghouse motor generators and frequency changers driven by induction or synchronous motors.

MOTOR GENERATORS

General Information

A motor generator is the combination of a direct-current generator driven through a common shaft by an alternating-current motor of the synchronous or induction type. Synchronous motors are of the same type of construction as synchronous generators of the same output and speed, except that the motors are provided with a squirrel-cage winding on the rotor for starting purposes.

If the design proportions are suitable the synchronous-motor-driven set may be reversible, that is, the motor may be operated as an alternating-current generator and the direct-current generator may be operated as a motor. Induction-motor-driven sets are not reversible. Synchronous motors require separate excitation which may be obtained from the direct-current generator, if the voltage is 250 volts or lower, from a direct-connected exciter or from an entirely separate source.

Application of Motor Generators—The synchronous motor is usually employed for the larger sets while the induction motor is more commonly found in the smaller sets. The induction-motor-driven set is best adapted for applications where simplicity is the most important consideration and where the lagging power factor of the induction motor is unimportant, as for example, in a small set installed in a mill location at some distance from the substation or power plant supplying the mill power. The induction-motor-driven set is also preferred for excitation service on account of the feeling that the induction motor is less liable to interruption than the synchronous motor and in case of interruption, can be put into service in a shorter time. This difference, however, has largely disappeared in modern sets having motors with cage windings of suitable design. The synchronous-motor-driven set is best adapted for application where leading power factor is desired and where the set can receive skilled attention during operation. It should be remembered that the principal advantage of the synchronous-motor-driven set that is, the ability to supply leading current to the line and so improve the power factor may become a serious disadvantage if the excitation of the motor is not properly adjusted.

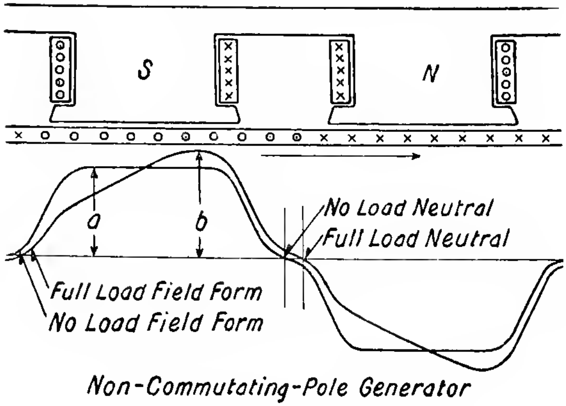


FIG. 1—NON-COMMUTATING-POLE GENERATOR

The Direct-Current Generators used in motor generators differ in no respect from other direct-current generators of the same output and speed. Shunt-wound generators are usually required for lighting and electrolytic service and compound-wound generators for railway or general power supply.

Commutating-pole generators are used practically without exception and compensating-pole face windings are also used in large units subjected to heavy overloads and load fluctuations.

Types of Direct-Current Generator Construction—There are two general types of construction, which are being used in direct-current machines: type using commutating poles only and the other type, which is a variation of the commutating-

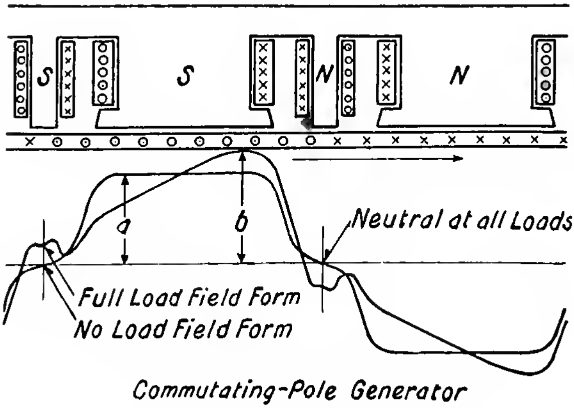


FIG. 2—COMMUTATING-POLE GENERATOR

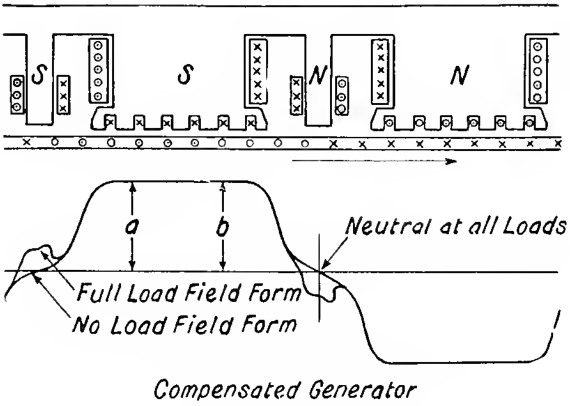
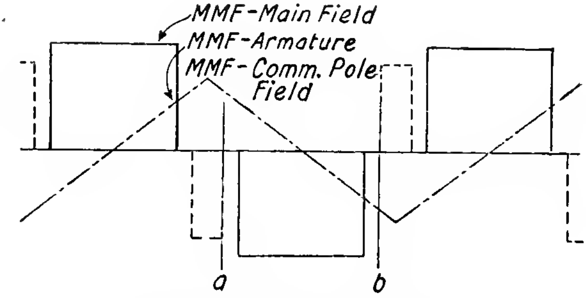


FIG. 3—COMPENSATED GENERATOR

pole type and which is called a "compensated machine" using a pole face winding in addition to the commutating poles. The commutating-pole machine is made by introducing additional small poles between the main poles. The small poles are magnetized by a winding which is in series with the armature and the brushes are so placed that the coil during commutation comes under the influence of the flux from the commutating poles, this flux being such value and direction that the cutting of it produces in the coil undergoing commutation, a voltage which neutralizes the voltage of self-induction. In a generator, the flux from the commutating pole must be in the same direction as the flux from the main pole immediately ahead and in a motor, the flux from the commutating pole must be in the same direction as the flux from the main pole immediately behind. An easy way for remembering this relation is to consider that in a generator, a piece of the main pole is moved BACKWARD instead of the brushes being shifted FORWARD, and in a motor, a piece of the main pole is moved FORWARD, instead of shifting the brushes BACKWARD.

This brings the neutral position midway between the main pole pieces, for either a motor or a generator, and by connecting the commutating-pole winding in series with the armature, a change from generating load to motor load automatically changes the polarity of the commutating poles. Thus, such a machine is suitable for either motor or generator operation, without any movement of the brushes. This characteristic is very important and it has opened a wide field of application, which could not be covered by the older type of machines.

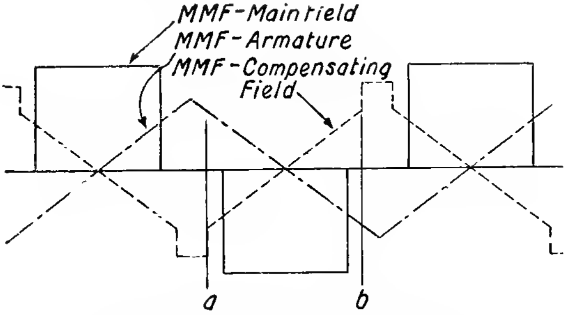
The next principal variation from the commutating-pole machine is the **compensated machine**; in fact, a compensated machine may be looked upon as a modified commutating-pole machine. The commutating-pole machine has the exciting winding concentrated about the commutating pole while the compensated machine has a part of the exciting winding distributed in the main pole face. The total excitation is the same in both cases. In the illustrations (Fig. 1 to 3), the direction of the currents and the shape of the magnetic fields are shown for the non-commutating-pole machine, the commutating-pole machine and the compensated machines.



MMF in Commutating-Pole Generator

FIG. 4—M.M.F. IN COMMUTATING-POLE GENERATOR

As the commutation-pole machine is simpler in mechanical construction than the compensated machine, the question naturally arises as to why the latter construction is used. In order to explain this, it is necessary to consider the function of the commutating-pole winding. Figures 4 and 5 show the magnetomotive forces which are present in both type of machines. The essential difference, as will be noticed from an inspection of the diagram, is that in the commutating-pole machine, the armature reaction is not neutralized in the zone "a-b," while on the compensated-pole machine the armature reaction is completely neutralized under the main pole. In order to maintain the best commutating condition, the flux from the commutating pole must change in exact proportions to the change of load. As soon as there is any saturation in the commutating pole, this exact relation is destroyed and the commutation limit is soon reached. It is therefore, undesirable to use shunts around either the commutating-pole winding or the compensating winding, as the presence of shunts may destroy the straight line relations between the armature current and the exciting current which produces the commutating flux. As the commutating-pole must carry both the useful flux for commutating and also any leakage flux which may be produced by its winding, it is evident that reducing the leakage flux will increase the commutating limit of the machine. The most effective way of reducing this leakage flux is to distribute the commutating-pole exciting field winding in the main pole faces and thereby increase the length of the path of leakage flux. This construction becomes what we have called the compensated machine and it possesses two distinct advantages over the plain commutating-pole machine. It has a greater maximum commutating capacity and the armature cross-magnetization is neutralized under the main poles, the maximum voltage between adjacent commutator bars is correspondingly less. By taking advantage of these points, it becomes possible, by the aid of compensation to increase the speed of generators and to make motors which will meet more difficult cycles of operation. Within the limits of commutation, the commutating-pole machine commutates just as well as the compensated machine, but the limiting factor in commutation is the saturation of the commutating-pole magnetic circuit, and the main factor in saturating this circuit is the leakage flux, and as there is less leakage in this part of the compensated machine, the overload limit is correspondingly increased.



MMF in Compensated Generator

FIG. 5—M.M.F. IN COMPENSATED GENERATOR

As the number of commutator bars per pole decreases with an increase of speed, a high average voltage between adjacent commutator bars is the result, and if the number of commutator bars is arbitrarily increased in order to obtain low average voltage between bars, the armature reaction is correspondingly increased, and the distortion of the main flux becomes greater, resulting in a high peak voltage between adjacent commutator bars. As has been shown in the compensated machine, there is no distortion of the main pole flux; consequently, with the same degree of safety, a higher average voltage between commutator bars is permissible. That is, with the same peak voltage between commutator bars, the compensated machine can have a higher average voltage between bars than the commutating-pole machine. Hence, for very high speeds, the compensated machine makes higher ratings possible. For the same reason, the compensated machine, for a given speed, makes higher voltage machines possible.

The pole face windings and the necessary connections for the same introduce a certain amount of complication, which is inherent to the compensating windings. It is a fact that the compensated machine is not as easily dismantled and not as easily repaired as the commutating-pole machine and for simplicity of construction and minimum number of parts, we must admit that the old non-commutating-pole machine is superior to either of the latter types.

Hence the better performance is obtained at a sacrifice of simplicity and a universal application of compensated machines would be as much of an error as would be an attempt to apply non-commutating-pole machines to all classes of service.

Three Wire Generators—The neutral wire for a three wire, two voltage system can be obtained from any Westinghouse generator by connecting collector rings to suitable points in the armature winding and connecting a balance coil between two collector rings.

The middle point of the balance coil is the neutral point to which the third or neutral wire of the system is connected. Two rings and one balance coil or four rings and two balance coils may be used depending on the space available for collector rings, the amount of unbalanced current, etc.

The commutating-pole windings and series-field windings in three wire generators are divided into two circuits (adjacent coils being in different circuits) one circuit being connected in the positive and one in the negative side. This is done to obtain the same excitation independently of the unbalancing. Consider the case of a generator with the series field in the negative side only and with all the load on the positive side. The current will flow from the positive brush, through the external circuit, back through the neutral wire without passing through the series-field winding.

Equalizers—As there are two series fields, two equalizer leads and brushes are required.

Ammeter Shunts are located at the generator in both negative and positive sides of the generator in order that the meters will indicate the current in both armature leads.

FREQUENCY CHANGERS

General Information—A frequency changer consists of an alternating-current motor, either of the induction or synchronous type, coupled to a synchronous generator of a different frequency.

The induction motor synchronous generator set is not reversible and is used mainly when some flexibility in speed is required. The synchronous-synchronous set is reversible, can be used for power factor correction on both ends and is generally preferred.

If a single frequency changer is used to supply a load of different frequency with a generating station only on the primary frequency side no new operating problems are involved. Under such conditions some odd frequency, such as 62½ cycles, is used on the load side in order to employ a higher speed. For 25-60-cycle transformation 300 r.p.m. is the highest available speed, which is unnecessarily low and expensive for sets under several thousand kva. With 25-62½-cycle transformation a speed of 750 r.p.m. may be used.

The commonly used speeds and the corresponding frequencies are shown in the following table:

Syn. Motor			**Syn. Generator**	
Cycles	**Poles**	**R.P.M.**	**Poles**	**Cycles**
25	4	750	10	62.5
25	8	375	20	62.5
25	10	300	24	60

With the induction motors for the 25-cycle end the generator frequencies will be reduced by an amount equal to the slip.

When a frequency changer is used as a tie between two generating systems of different frequencies or several sets are operated in parallel several new operating problems are involved. When a set ties together two existing systems the set must be large enough to control the speed of the smaller system in case appreciable fluctuations in speed of either system occur, or the two systems will pull apart and the frequency changer will fall out of step.

In the case of two or more sets operated in parallel, starting and synchronizing the second set introduces new problems of considerable importance. These will be considered in detail, under **Operation of Frequency Changers.**

GENERAL INSTALLATION INSTRUCTIONS

Mechanically the motor generator and the frequency changer are very similar and the following instructions will apply to the various types of both kinds of sets except when they are limited to a single type by the context.

General Precautions—Upon receipt of the cases containing the machines or their parts, place them in a dry and sheltered position. Do not open them, and disturb them as little as possible until everything is finally ready for assembling.

It is easily possible by rough handling or careless use of bars or hooks to do more damage to a machine before or during erection than it would receive in years of regular service. Bear in mind that the armature of a direct-current generator is liable to damage, since its own weight is sufficient to crush the winding, if it is lowered on or swung against a projection.

Care must be exercised in handling and installing electrical machinery of any type.

As moisture is an enemy of the insulation, a machine or insulated part should not be allowed to stand where it can absorb moisture from the air or any other source.

A blow of any sort upon any part of the winding, or intrusion in the machine of water, pieces of wire, tools, nuts or foreign substances of any kind, by accident or otherwise, may cause a breakdown or burn out, and should be avoided.

It is desirable that all sets be assembled, installed and placed in operation under the supervision of an experienced engineer. No printed instructions, however complete, can take the place of actual experience.

Unpacking--When a set is shipped entirely assembled, all boxing or crating should be removed, and the machine is then ready for setting up and drying out. In cool weather, the packing and wrapping should not be removed until the apparatus has been in the room long enough to come up to the temperature of the air

If this precaution is neglected the apparatus will sweat and sufficient moisture may condense upon the windings to weaken the insulation, and cause a breakdown.

When a machine is unpacked it should be carefully examined to determine whether any damage was received in transit and if all parts and accessories are present in proper condition and position.

Save the shipping notices sent when the apparatus is shipped as they give the number of our shop orders on which the apparatus has been built and this "S. O." number is an excellent means of identification. It materially assists in quickly locating all records regarding the parts.

Location of Machines—It is of the greatest importance in laying out a power house or substation that the location of the sets be governed largely by the following considerations:

(1) The machines should not be exposed to moisture from leaky pipes, escaping steam or condensation of atmospheric moisture on overhead glass or a metal roof.

(2) They should not be exposed to the corrosive action of acid fumes or other injurious gases.

(3) They should not be exposed to dirt from coal handling or similar causes.

(4) Since the total temperature, and consequently the capacity of the machine, depends upon the temperature of the surrounding air, it is evident that the location should be in a room as cool and well ventilated as is consistent with proper protection from dirt and moisture.

(5) The position of the set should always be such that the commutator and collector rings, which require special attention, are readily accessible for inspection.

Foundations—Wherever possible, solid masonry or concrete piers should be used so as to prevent vibration and minimize the wear on the bearings and brushes.

Be sure that the foundation is carried down to a solid bottom, or is made of sufficient area to prevent sinking or displacement under the full load it is expected to support.

A competent engineer who is familiar with local conditions should lay out this part of the work.

Care should be taken that all pits in the concrete are properly drained and that passages remaining for piping and wiring are easily accessible and so laid out that the work in installing and connecting up will be simplified in every possible way.

INSTALLATION OF MOTOR GENERATORS

No definite instructions can be given to cover the installation of motor generators, since conditions in different cases will vary widely, due to crane facilities, the condition of the floors or other parts of the building, kind of foundations, and the available material for the assembling work. A few suggestions, however, will be given, but the actual procedure in any particular case must be left to the resourcefulness of the erecting engineer.

Some of the smaller sets are shipped completely assembled. Obviously, the installation of such sets requires little work by the erector, except properly grouting the bedplate on its foundation. The larger sets are shipped completely disassembled and require skilled supervision during erection.

Erection of Pedestal Bearing Sets Shipped in Parts—

(1) Set the bedplate on its foundation and level it by wedging. The bedplate should be first levelled in both direc-

tions by means of a spirit level. Care should be taken particularly in three-bearing sets that in levelling the bedplate, the bedplate is not sprung, and the bearings thereby thrown out of alignment.

In some cases, the pads on the upper side of the bedplate for supporting the bearing pedestal are on different levels and before starting work, differences in the level of these pads, if any, should be determined. The planned surface on the under side of the bedplate can always be used as a reference surface for levelling. Short pieces of cold rolled steel, placed under the bedplate and wedged against its bottom surface, can be used as a support for the straight edge and spirit level. If the pads for the pedestals are on different levels, and the differences are known, distance pieces of the proper thickness can be placed on each pad, and the bedplate can be levelled up from the top surface.

In cementing the bedplate to the foundation use a mixture of one part of Portland cement and two parts of sand, or half cement and half sand; either will give good results. First mix the cement and sand dry and then add water until a very thin solution is obtained. Construct a dam around the bedplate and pour this about half-an-inch above the bottom of the bedplate. The entire operation of mixing and pouring the cement should be carried on without interruption and as rapidly as possible until completed, otherwise the cement first poured under the bedplate may partially set and prevent that poured later from flowing freely to all parts. When the cement has sufficiently hardened, remove the surplus from the outside and smooth up the joint under the bedplate.

The bedplate supplied with the larger motor generators are of the open type with solid bridges on the generator end, and at the center between the two units. On the motor end, the bedplate is open, and the bearing pedestal is supported by a removable bridge which is ream dowelled to the bedplate. Motor generators do not require foundation bolts and no holes are provided for them in the bedplate.

When the bearing pedestal and bridge are removed, the motor stator can be shifted outward for inspection and repairs. This applies to either two or three bearing sets, the rotor must be supported by a jack resting on the center bridge.

In the largest sets, sliding shoes are provided under the frame feet, the shoe tongue sliding in a groove in the bedplate.

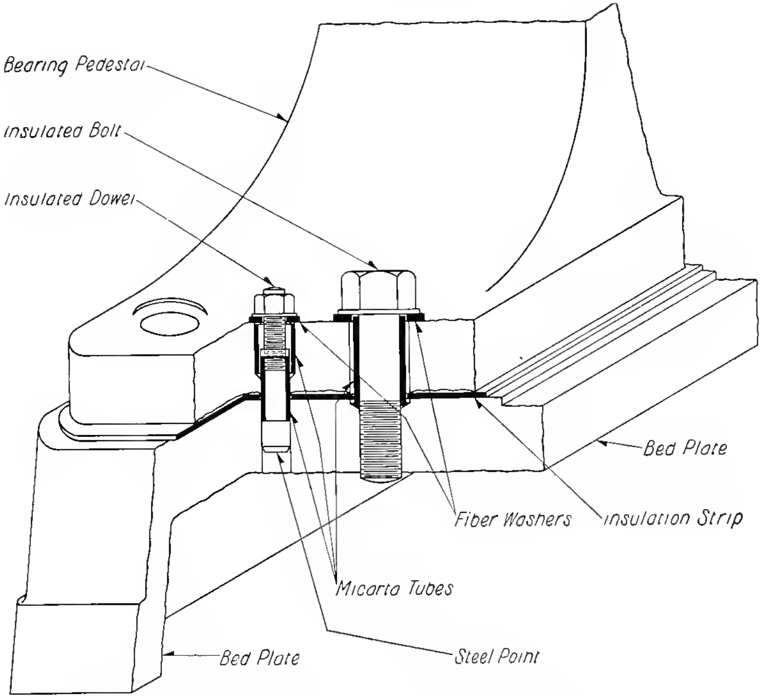


FIG. 6—METHOD OF INSULATING BEARING PEDESTAL FROM BED PLATE

The frame is adjusted at right angles to the shaft by bolts and set screws in the frame feet. In all other sets, the frames are ream-dowelled to the bedplate, so that lateral adjustment is unnecessary.

The bearing pedestals and bedplate are numbered consecutively, adjacent parts bearing the same numbers. Adjacent parts of the frame feet and bedplate also bear the same numbers. In assembling these parts, see that adjacent numbers are the same. If the frame liners are shipped in one bundle, place half under each frame foot; when two bundles of similar liners are shipped, it is because one foot required one or two more liners than the other. Each package of liners will then be marked to identify its proper location.

Under some conditions in the operation of a set, a difference of potential along the shaft is set up which would cause current to flow through the circuit composed of the shaft, bearings, pedestals and bedplate. This current may be sufficiently large to pit the shaft and journal, and cause bearing trouble. In order to prevent this, the bearing pedestal at the motor end is insulated from the bedplate. The method of insulation is shown in Fig. 6. Bolts and dowels are insulated, as well as the main surface between bedplate and pedestal. The insulated dowels have a steel point for driving, which is followed by a protected micarta insulating tube. The bolts are insulated with micarta tubes and washers. The pedestal and insulation bearing the same numbers should be assembled together. When the insulated dowel is driven to position, it is necessary that the micarta tube crosses the joint between the pedestal and the bedplate.

(2) After the bedplate has been levelled and properly aligned, the pedestals should be put in position and alignment of the bearings themselves should be checked.

Small differences in the level of the bedplate and bearings as a whole are relatively unimportant, but great care must be exercised that the alignment of the different bearings is correct within a few thousandths of an inch.

Lateral alignment of the bearing pedestals is unnecessary, as this adjustment is taken care of at the factory and the pedestals are ream dowelled to the bedplate.

(3) After the pedestals have been placed in position the lower half of the direct-current generator frame should be placed on the bedplate. In most cases, the motor frame is solid, and it will be most convenient to place the motor frame in position after the rotor has been placed in position. When the motor frame is shipped in halves, it will be necessary to connect the coils across the split in the frame, either before the motor frame has been placed in position on the bedplate, or with the motor frame shifted clear of the motor.

All the bearing pedestals must be placed, bolted and dowelled, and the removable bridge bolted and dowelled before the rotor can be placed in the bearings.

Remove the protective coating from the shaft, wipe the journals clean and dry and cover them with a film of oil; see that the bearings are thoroughly cleased of grit and dust and cover with a film of oil; place the rotating part into the bearings, see that the oil rings are in position, put on the upper half bearing and see that the oil rings are free to move. Fill the bearings with oil to the proper level, put on the bearing caps and screw down the bolts. Do not tighten the bolts until after the rotor has been turned over and the operation of the bearings found satisfactory.

When handling the rotor always support it by means of rope slings about the shaft, taking care that these do not come in contact with the windings or mar that portion of the shaft which normally rests in the bearings. Any roughness at this point would cut the babbitt of the bearings and cause undue heating when the machine is in operation.

Never under any conditions support the weight of the rotor from the commutator or collector rings, either by ropes or blocking. In putting the rotor into position be careful not to scratch the bearings or bend the oil rings.

(4) Clean the contact surfaces of the generator frame and secure the upper to the lower half by means of the bolts and feather keys.

(5) Assemble the direct-current rocker ring with the carbon holders in position. The carbon holders are bolted to the brackets and the brackets in turn are securely bolted to the rocker ring. It is not necessary to disassemble these parts; if they are, the work of determining the correct commutating position of the brushes is greatly increased.

(6) If the motor frame is solid, or if the coils are connected across the split before assembling the stator with the rest of the set, block the shaft from the center bridge (in the case of a two bearing set) and remove the outer bearing pedestal and supporting bridge. Place the motor frame in position, and replace the bridge and pedestal. In the case of a three bearing set, remove the outer pedestal and bridge and slide the motor frame in position.

(7) Before starting up the set, test the air gap, using steel strips for feeler gauges. If the set has been correctly assembled, no adjustment of the air gap should be necessary, except possibly in the case of sets in which the frame feet are supported on sliding shoes. In such cases, the air gap should be adjusted, if necessary, by means of the bolts and set screw in the frame feet.

(8) In sets having a direct-connected exciter or starting motor with an outboard bearing and with a separate shaft which is bolted to the main shaft it is very important that the supporting bracket and outboard bearing be accurately aligned with the main bearings and the supporting bracket be rigidly supported. **Failure to properly install these parts may result in the fracture of the small shaft near the coupling end.**

(9) Connect up the field, the alternating-current and the direct-current armature leads. Insert the brushes in their holders, grinding them in with sandpaper. See Fig. 7. See that the brushes move freely in the holders and are held under an equal and moderate pressure. Connect the machine to the

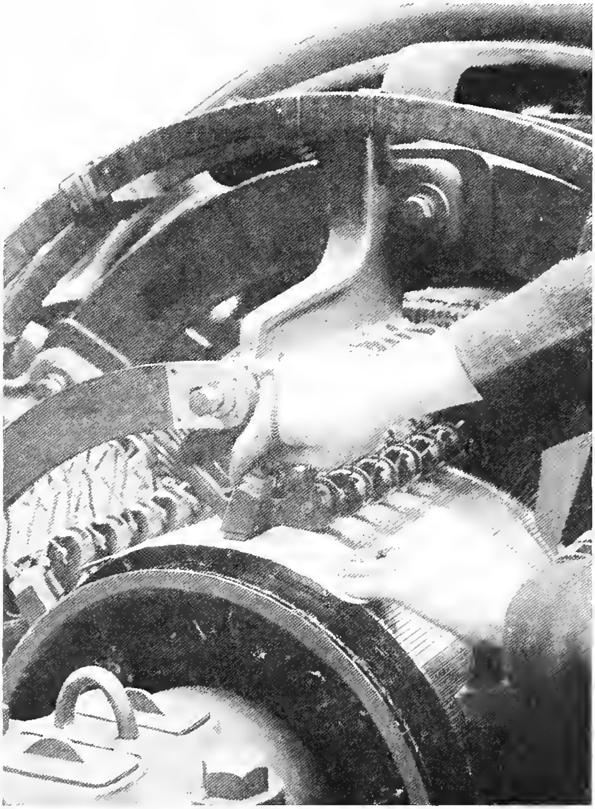


FIG. 7—GRINDING BRUSHES OF D.C. GENERATOR

switchboard including the connections of the overspeed device, when supplied, to the direct-current circuit-breaker.

Drying Out Insulation—If the armature or field coils have been exposed to low temperatures during shipment or storage, they should be allowed to come up gradually to room temperature before they are unpacked as otherwise moisture from the warmer atmosphere will condense upon the cold surfaces, sometimes in sufficient quantity to materially weaken the insulation. If the windings have become damp either in this manner or through exposure to snow or rain they may be dried out by one of the following methods.

Drying Out D. C. Generators—

(1) Drive the generator by the motor or from some external source, such as a separately belted motor, and short-circuit the armature, beyond the ammeter using a very weak field excitation. If the generator is shunt wound, low voltage separate excitation must be employed; if compound wound the armature may be short-circuited through the series field coils.

Direct-current generators are very sensitive when operated as series machine and there is danger of generating an excessive current. Consequently this method should be undertaken only by experienced operators.

(2) The field coils may be dried by applying from some Separate source of excitation approximately two-thirds of the normal direct-current voltage.

There is always danger of serious injury to the windings when drying out with current since the heat generated in the inner parts is not readily dissipated; furthermore, coils containing moisture are much more susceptible to injury from overheating than when thoroughly dry. The temperature of all accessible parts should be carefully observed during the drying out process and never allowed to exceed 80 degrees Centigrade, total temperature. Several hours or even days may be required for thoroughly drying out large machines.

During the drying out process the temperature should not be allowed to drop below that of the surrounding air as moisture then condenses on the coil surfaces and the effect of the previous drying would be largely lost.

During the drying out run readings of the insulation resistance (see page 20) should be taken at regular intervals and plotted as a curve, using time for the horizontal scale and resistance for the vertical scale. The drying out should continue until the resistance has begun to increase. If the insulation contains appreciable moisture the resistance will decrease during the first part of the drying out process.

Heating windings by current is more effective than any process of heating from the outside, such as enclosing the machine and heating the air by resistance or fires, because in the former method the inside of the coils becomes hotter than the outside and moisture is driven outward. With external heating the reverse is true.

Drying out Synchronous Motors and Generators—Synchronous motors and generators can be dried out by rotating the motor or generator at any convenient speed and short-circuiting the armature beyond the ammeters. The field should be excited so that the desired heating current will flow in the armature winding. For windings of 2400 volts or lower, the temperature, as measured by thermometers properly applied to the hottest accessible part of the winding should not be higher than 80 degrees Centigrade. For 6600 volt windings the temperature should not be higher than 75 degrees Centigrade and for 11000 and 13200 volt windings the temperature should not be higher than 65 degrees Centigrade. The reason for specifying lower temperature for the higher voltage windings is the greater difference in temperature between the inside of the coil and the outside (when the temperature is measured) in the coils having the thicker insulation.

If a low voltage (5 to 15 per cent of normal) can be obtained, from taps on transformers for example, the armature winding can be dried out by applying this low voltage to the armature terminals, the rotor remaining stationary. The field winding should be short-circuited and the temperature of the cage-winding on the rotor should be watched. Less than normal current will be necessary on account of the absence of ventilation.

Drying Out Induction Motors—Induction motors can be dried by operation at no load and low voltage (the primary current and heating increases as the voltage is reduced) or by the application of a still lower voltage that will circulate a sufficiently heavy current at a standstill If a suitable low alternating voltage is not available direct current, if available, may be used. Lacking any source of current the motor can be dried by enclosing it as completely as possible by wood or canvas and heating the enclosure by gas or charcoal.

Insulation Resistance Test—The insulation resistance of a winding gives an indication of its condition as to moisture and dirt and this test should be made on all windings before a machine is subjected to the operating voltage. The insulation resistance is at best only a rough guide and relative values in the same winding (as during a drying out run) are of more value than the relative values of different windings.

The insulation resistance of a machine in good condition and at its operating temperature will usually be not less than the value given by the following formula.

$$\text{Insulation Resistance (in megohms)} = \frac{\text{machine voltage}}{\text{rated KVA.} + 1000}$$

For example a 1000-kva. 11000 volt motor should have an insulation resistance, if clean and dry, of 5.5 megohms.

The insulation resistance of field windings will, in general, be much higher in proportion to the operating voltage than that of the armature. The insulation resistance of any machine will be much lower when hot than when cold, especially when the machine is heated rapidly.

The insulation resistance may be tested by a megger, an instrument especially designed for this work, or if this is not available, measurements may be made in the manner indicated by Fig. 8.

The line voltage is first read by connecting the middle and upper terminals of the double-throw switch; the voltmeter is then read with the double-throw switch connecting the middle and lower terminals which places the voltmeter and insulation resistance in series. A 500 or 600-volt circuit should be used as the insulation resistance varies to some extent with the applied voltage.

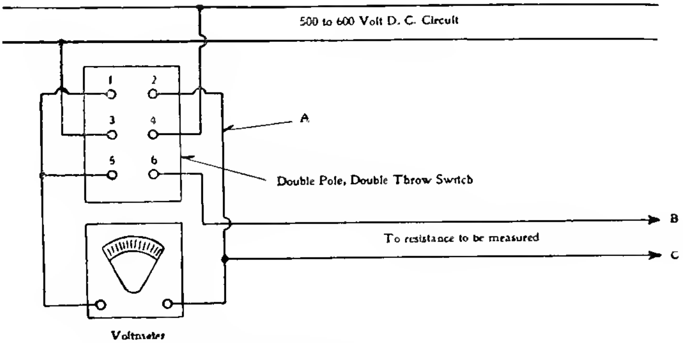

500 to 600 Volt D. C. Circuit
1
2
3
4
5
6
A
Double Pole, Double Throw Switch
B
To resistance to be measured
C
Voltmeter

FIG. 8—CONNECTIONS FOR MEASURING INSULATION RESISTANCE

The resistance is then calculated by using the following formula:

$$R = \frac{r\ (V - v)}{v\ (1{,}000{,}000)} \text{ in which}$$

V = voltage of the line.

v = voltage reading with insulation in series with voltmeter.

r = resistance of voltmeter in ohms (generally marked on label inside the instrument cover).

R = resistance of insulation in megohms (1 million ohms).

If a grounded circuit is used in making this measurement care must be taken to connect the grounded side of the line to the frame of the machine to be measured, and the voltmeter between the windings and the other side of the circuit.

Voltmeters having a resistance of one megohm are now made for this purpose so that, if one of these instruments is used, the calculation is somewhat simplified, since $r = 1{,}000{,}000$ and the above formula becomes

$$R = \frac{V}{v} - 1$$

Test of Dielectric Strength—The high voltage or "breakdown" insulation test is invariably made at the factory and it is neither necessary nor desirable that it be repeated after installation. When high voltage test appear to be necessary the manufacturer should be advised before such a test is made. High voltage tests when made after installation should be made before machines are placed in service and should not be applied when the insulation resistance is low owing to dirt or moisture. **Test voltages appreciably higher than the operating voltage should not be applied to repaired windings** and even when the winding has been completely replaced the test voltage should be lower than that specified for a new machine.

Connections—Figs. 39-44 inclusive show typical wiring diagrams of motor-generator installations.

The wiring diagram for any particular installation should be obtained from the manufacturer of the switchboard.

All wiring should be installed in accordance with the rules of the National Board of Fire Underwriters.

Exceptional precautions must be taken in running wires for high tension service. So far as possible, all circuits should be out of normal reach and so placed as to minimize any danger from mechanical injury or from contact with other electrical circuits.

All wiring should be exposed and rigidly supported on suitable insulators. Lead covered cables for high potential are to be avoided unless absolutely necessary; when they are used, additional precautions must be taken to insure proper insulation.

Equalizer Leads—In compound-wound direct-current generators operated in parallel, an equalizer lead is required. With grounded railway circuits, it is desirable to have the equalizer connection made on the negative or grounded side of the generator since with this arrangement it is unnecessary to carry the equalizer connections through the switchboard and the wiring is greatly simplified. This is the standard arrangement in Westinghouse generators.

For an explanation of the purpose of the equalizer connection see page 42.

The equalizer lead should have small resistance. It is the usual practice to make the equalizer leads not less than one-half the size of the main leads. In installations where long equalizer leads are necessary, a larger equalizer may be advisable in order to maintain a sufficiently low resistance.

Series Shunt—A series shunt consists of a low resistance connection across the terminals of the series field, by means of which the compounding effect of the series winding may be regulated by shunting more or less of the armature current past the series coils. It may be in the form of grids, on large machines, or of ribbon resistors on smaller machines. In the latter case it is usually insulated and folded so as to take but a small amount of space.

Main Leads—In laying out the wiring of several compound-wound generators that are to operate in parallel particular attention should be paid to the relative resistance of the several circuits.

If the generators are of the same size and make the only feature requiring special attention that all the cables which lead from the various machines to the bus-bars be of equal resistance. This means that if the machines are at different distances from the switchboard, the same length of cable should be used for each generator or resistance inserted in the low resistance leads.

If the generators differ in design or size, the matter requires more attention. In this case the difference in potential or drop in voltage between the terminals of the machine and the bus-bars to which they are connected should be exactly the same for every generator when each is carrying its proper share of the load. To secure the best results, the total drop between generators terminal and switchboard must not only be the same at equal loads, but the drop in corresponding sections of the connecting cables of the different machines should also be equal; i. e., the drop in the positive lead from any one generator at full load should equal the drop in each of the other positive leads when carrying full load. The same coudition should be secured in the negative lead, in the equalizer connections and in series field windings. It may be necessary in achieving the desired results to alter the length or size of connecting cables, and occasionally to add resistance to some of the circuits.

Balance Coil Connections of Three Wire Generators—Wires connecting the balance coil to the machine must be short and of low resistance. Any considerable resistance in this connection will affect the voltage regulation. The unbalances current flows along these connections; consequently, if they have much resistance, the resulting drop in potential reduces the voltage on the heavily loaded side.

Switches are not ordinarily placed in the circuits connecting the collector rings to the balance coil. When necessary the coil may be disconnected from the generator by raising the brushes from the collector rings. Switching arrangements often make it necessary to run the balance coil connections to the switchboard and back, requiring heavy leads to keep the drop low; or if heavy leads are not used, then poor regulation may result. The balance coils are so constructed that there is very little likelihood of anything happening to them which will not be taken care of by the main circuit-breakers.

Alternating-Current Motor Phase Rotation—In order that the alternating-current wiring connectings between the motor and its supply circuit may be correctly made to obtain a given direction of rotation, it is necessary to know the phase rotation of the motor and the supply circuit. By "phase rotation of the motor" is meant the order in which each phase reaches its maximum voltage of one polarity.

All Westinghouse motor generators are arranged for clockwise rotation, looking at the commutator end. With this direction of rotation, the phase rotation is given by the order of terminal notation. Using letters to designate the terminals, the order for three-phase machines is B-C-A and for two-phase B_1-A_1 B_2-A_2.

The sequence of phase rotation of the supply system can be found by tracing the wiring back to the generator station or else by the use of a phase rotation indicator.

In case of sets having flexible cable leads on the alternating-current side, the simplest method of determining the proper order in which to connect the motor leads is to connect the leads in any convenient order and start the motor. If the direction of rotation is opposite to that desired reverse any two leads in the case of a three phase motor or interchange the two leads of either phase, in the case of a two phase motor.

Resistance in Feeders—With circuits subject to frequent and severe short-circuits, such as in many railway installations, it is desirable to connect the feeders from substations to the trolley (or other distributing line) at some distance from the substation, in order to have some resistance between the generator and the point of short-circuit even when the short-circuit occurs directly at the point of feeder and trolley connection.

In some cases the same result can be more conveniently obtained by inserting grid resistors in the feeders within the substation.

In deciding whether this resistance is necessary, it must be remembered that any commutating machine will "buck" on dead short-circuit. The only question involved is whether the number or severity of the short-circuits to be expected requires the resistance in order to protect the service from interruption.

Direct-Current Generator Brush Position—In non-commutating-pole machines the correct running position of the brushes is "ahead" of the no load neutral and is found by trial. In commutating-pole machines the brush position is fixed and the correct adjustment is determined at the Works before shipment

This correct position is made permanent by dowelling the rocker ring to the frame.

Location of Neutral Point—The no load neutral point on the commutator is that point at which a minimum voltage is induced between bars when the machine is running without load with only the main pole windings excited.

In case it is necessary to check the location of the neutral point one of the following methods should be followed:

On non-commutating-pole machines the neutral should be found while running the generator as a shunt motor or by driving the machine by some external power with the shunt field winding excited. Use a low reading voltmeter with 0.5—1.5 and 15 volt scales preferable. Use two-pointed leads for the meter. Hold the points one commutator bar width apart on the commutator and move them along until the point of minimum voltage is located. This method is not the most accurate, but is usually satisfactory for non-commutating-pole generators.

For commutating-pole generators there are two methods, either of which, if properly used, is sufficiently accurate although the "running" neutral method is most commonly used.

First—The "Kick Neutral"—This method is based on the fact that when the field circuit of any direct-current machine is opened, an induced voltage is generated in the armature windings. In case the brushes are in the exact neutral position the resultant voltage so generated is zero.

In checking this, set the brushes as close as possible to the mechanical neutral position. For commutating-pole machines this position is determined by setting a given armature slot in the center of the commutating pole and then moving the rocker arm until the brushes on one arm cover the commutator bars which are connected to the conductors in the slot. For machines without commutating poles a given armature slot should be set as near as possible at the center of the space between the main poles and the brushes set on the corresponding commutator bars. Raise all brushes and insert on each arm one brush whose face has been bevelled to practically a knife edge so each brush touches one commutator bar only. This edge should be parallel to the brush arm and in the center of the face of the brush. Arrange to separately excite the shunt field from any convenient source of power with a quick break switch in the circuit. A low reading voltmeter should be used as before.

Open and close the field switch and note deflection on the meter. The deflection, if any, will be only a momentary "kick." If the voltage is not zero it indicates that the brushes are not on neutral and they should be moved by shifting the rocker ring to such a position that no deflection will be obtained on the voltmeter when the field is opened or closed.

Second—"Running Neutral"—This method is based on the fact that if the brushes are in the correct no load neutral position, no active electromotive force will be generated by the commutating-pole flux when the machine is running on open circuit with the commutating windings separately excited.

Bevelled brushes should be inserted, one in each arm, as in the previous method, except that the faces of these brushes must be wide enough to bridge one mica segment. The face of the brush must be ground in for good commutator contact and must not be wide enough to make contact with more than two commutator bars with any commutator position. A reversing switch should be connected in the separately excited shunt-field circuit and some arrangement made for exciting the commutating-pole winding at from two to four per cent of its normal current. The commutating-pole circuit should be disconnected from the armature, and the armature open circuited. Use a low reading voltmeter (such as was suggested for the "kick neutral" method) across arms of opposite polarity. Bring up to approximately normal speed and by exciting the main field for an instant only, in a reverse direction, demagnetize it entirely, that is, until no deflection shows on the lowest scale of the voltmeter. Any deflection then obtained by exciting the commutating poles will be due to the commutating-pole flux alone. First excite the commutating-pole windings with about 2 per cent of their normal current and shift the brushes until no deflection is obtained on the lowest scale of the voltmeter. Check the residual magnetism of the main poles from time to time keeping it at as low a value as possible by demagnetization as explained above. After determining the best location for the brushes at this excitation raise the commutating-pole current to about 4 per cent of normal and check results. If no difference is found reverse the current in the commutating pole and try again, still checking the residual from time to time. In some cases higher currents may be used, but the leakage flux soon becomes large enough to destroy the symmetry of the normal field form and inaccurate results will be obtained.

This method, if used carefully, gives very accurate results. It may be noted that the position of the brushes is at the peak of the commutating-pole field form and as this peak is rather sharp the effect of displacement will be very marked. Since the machine is running, errors due to brush resistance or to a brush resting on mica only, are entirely eliminated, making this method preferable to the "kick method."

Grinding in Brushes — The ends of the carbon brushes should be carefully fitted to the curvature of the commutator; this can be done by putting sandpaper under each brush while pressing it firmly against the commutator as shown in Fig. 7. The sandpaper should cut the brush only on the forward stroke, and in the direction of normal rotation. Copper-plated brushes should have their edges slightly bevelled in order to prevent the copper sheath from scratching the commutator.

Adjustment of Direct-Current Brushes—The direct-current brushes are usually of the graphite type. This grade of brush is practically free from carbon or hard gritty material. Among its important characteristics are—high current carrying capacity, high lubricating quality, low friction coefficient and consequently low friction losses, and low resistance drop.

The absence of abrasive qualities makes this type of brush unsuited for non-undercut commutators, where the mica must be worn down by the brush. The low resistance drop also makes it in some cases unsuited for non-commutating-pole machines which inherently have relatively high voltage induced in the armature coils undergoing commutation, producing large currents in the low resistance brush face.

The brushholder arms and brushholders are correctly spaced and adjusted before the machine leaves the Works, but due to subsequent disassembling or rough handling during shipment, they may be displaced. These adjustments should be checked, in all cases, before the machine is put in service. The brushholder arms should be parallel to the commutator bars; the brushholder should have a clearance between the surface of the commutator and the bottom of the holder of approximately 1-8 inch; and the relative spacing of the brush arms around the commutator, as determined from the edges of the brushes, must be uniform. The preferable method of checking this latter point is to stretch a piece of paper tape around the commutator under the brushes, allowing the ends to overlap to some extent. Care must be taken that it is smooth and parallel with the edge of the commutator at all points. Make a fine clear mark with a sharp pencil on the tape exactly at the toe of the brush on each arm resting on the tape. Some marks of identification should also be made so that, after removing the tape from the machine, the arms corresponding to the marks may be readily identified. Remove the tape and measure the space between the marks, adjusting the arms until approximately equal spacing results. Brushes must be ground in as indicated in the preceding paragraph before spacing brushes. The difference in spacing should not be more than 1-16 inch. The brushholder springs should be adjusted to a uniform tension of from one to two pounds per square inch of

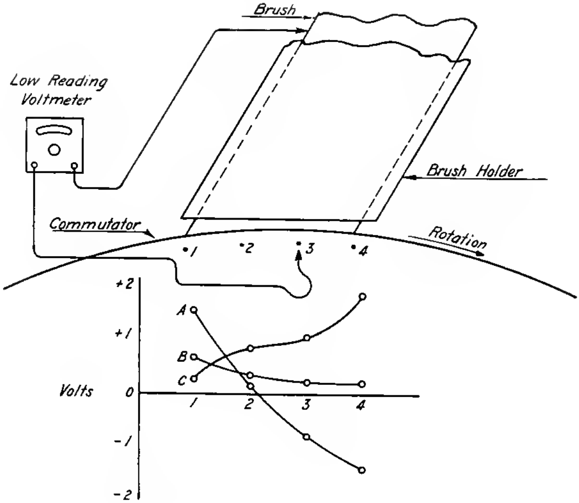


FIG. 9—ARRANGEMENT FOR DETERMINING PROPER ADJUSTMENT OF COMMUTATING-POLE FIELD

brush contact, depending on the grade of brush and condition of operation. The softer graphite brushes should be operated with the lower tension.

Adjustment of Commutating-Pole Field—The commutating-pole adjustment to give the best commutating conditions is made at the Works and, in general, no reason for changing it after the generator is installed will arise. However, if such reasons should arise the proper change in excitation may be determined as follows:

(1) With a low reading voltmeter read the voltage between the brush and the commutator at four equidistant points along the width of the brush (along the circumference of the commutator) when the machine is running at normal load and voltage. These voltages can be most conveniently read by inserting a hard wood or fibre block in an end brushholder having four radial holes correctly spaced in which the voltmeter "point" can be inserted. This is shown in Fig. 10.

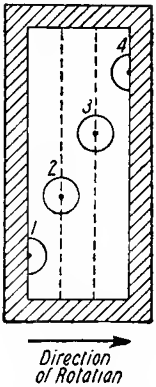


FIG. 10—PROPER POINTS FOR READING VOLTAGES

Readings should be taken from 1 to 4 in the direction of rotation. Take curves under both positive and negative brushes for several brush arms.

These readings if plotted as shown in Fig. 9 indicate for example in curve A over compensation; i. e., excessive commutating field strength; curve B correct compensation; curve C under compensation.

(2) Changes in commutating-pole strength to secure correct compensation can be made by changing the air gap or by shunting part of the current from the commutating-pole winding. Adjustment by changing the air gap is the more usual method. In case of over compensation the air gap should be increased and in case of under compensation the air gap should be decreased. When adjustment is made by shunting, an inductive shunt, having approximately the same ratio of self-induction to resistance as the commutating-pole winding is advisable. This insures proper division of current between the field winding and shunt when the load suddenly changes.

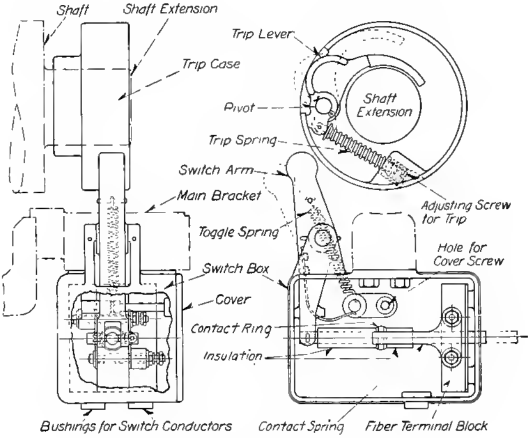


Fig. 11—Speed Limit Device Details

The measurement of brush curves and the adjustment of the commutating-pole strength should only be undertaken under the supervision of an experienced engineer.

The Speed Limit Device—A speed limit device, consisting of a spring closed switch, is attached to the shaft, in some sets. When the set reaches a certain speed above normal, a centrifugal governor mechanism operates the switch and opens the circuit breakers, thus cutting off the motor from its source of supply and the generator from its load.

To Reset the Switch—It is merely necessary to move the switch arm back to the normal position by hand. This can readily be done at any time whether the machine is running or not and without opening the switch box.

Assembly of Speed Limit Device—All speed limit devices are set and tested at the Works. The switch box complete is shipped attached to pedestal. Bolt up parts in place, fasten the trip case to the shaft, next push in the switch arm; there should be at least 1-8 inch between the switch arm and the trip case.

Adjustment of Speed Limit Device—All standard sets are provided with a test pulley extension on one end of the shaft. When testing for overspeed the generator can be run as a motor or the set can be belted to a motor on the pulley end. It is important to have complete control of the speed during test. Use a tachometer or any reliable direct reading speed indicator, but do not use the ordinary revolving dial indicator.

Then test for overspeed; the switch should trip at about 15 per cent above rated speed. Bring the speed down slowly and watch for the trip in speed of governor trip lever.

Should it be found necessary to reset the governor proceed as follows:

First determine the tripping speed, assemble the governor as shown in Fig. 11. Screw in the adjusting screw even with the governor case, and give the screw about one-half turn inward at each run until it trips at the overspeed. Then tighten the small locking screw on the side of the trip case.

Before startiug each test see that the switch arm is in and pull the trip lever several times by hand to see that it works freely.

Inspection—Speed limit devices should be operated at regular intervals as a part of the routine inspection to insure that all parts are operative and all circuits complete. Failure to properly maintain the overspeed device and wiring may result in the loss of a machine.

●

INSTALLATION OF FREQUENCY CHANGERS

The instructions for the installation of motor generators (see pages 13 to 32) should be followed where applicable and except as modified below.

Speed Limit Devices are not necessary with frequency changers since overspeed can only occur through the very improbable overspeeding of the entire system to which the frequency changer is connected.

Installation of Oil Pressure System for Starting—In the largest frequency changers the starting current taken by the set may be very considerably reduced by lifting the rotating part from its bearings by oil pressure before the starting switch is closed.

When in operation the shaft is not in contact with the babbitt of the bearing but is carried on a thin wedge-shaped oil film. When the shaft is at rest this oil film is squeezed out and the journal rests upon the bearing surface in metallic contact. This friction coefficient, when running, will be of the order of 1 per cent of the friction coefficient that exists when the bearing and journal are in metallic contact. If, therefore, oil can be forced **under** the journal, before it begins to turn over, the torque, and current required to start the set can be very considerably reduced. Obviously, oil supplied to the upper surface of the journal, as in a gravity oil feed system for lubrication, will have no appreciable effect in reducing the torque at starting. A high pressure, in the neighborhood of 1000 pounds per square inch, is required to actually lift the rotating part and provide an oil bearing surface for the journal. The reason for such a high pressure, in comparison with the usual running pressure which is in the neighborhood of 100 pounds per square inch, is found in the difference in bearing surface in the two cases. This is illustrated in Fig. 12 which shows the pressure diagram for running (in dotted lines) and for starting (in full lines). In the case illustrated oil for raising the rotor is introduced into the bearing through a single hole at the center of the bearing. The area is small, as compared with the total projected area of the journal and the pressure required is cor-

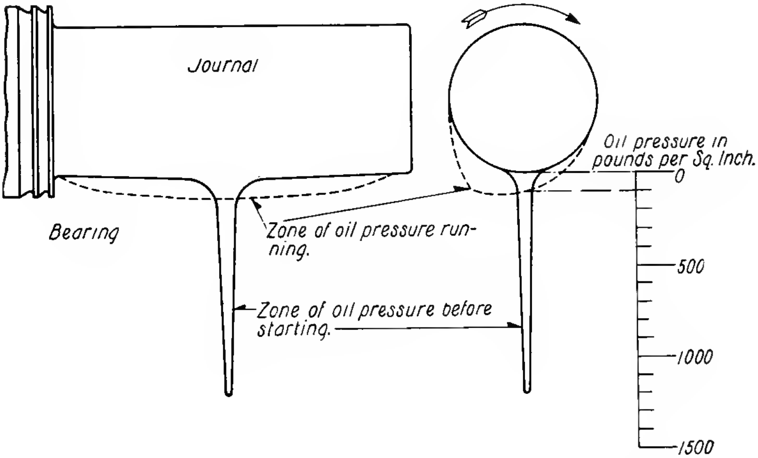

Journal
Bearing
Zone of oil pressure running.
Zone of oil pressure before starting.
Oil pressure in pounds per Sq. Inch.
0
500
1000
1500

Fig. 12—Distribution of Oil Pressure When Running Upon an Oil Film

respondingly high. In other cases, a slot is provided that extends the full length of the bearing; with this greater area the necessary pressure is reduced and the condition of a perfect oil film is more nearly approached. The total resultant upward pressure of the oil must be approximately the same before starting as it is during running assuming that the rotor is actually lifted and supported by oil pressure in each case.

The **equipment** required for oil pressure starting consists of a motor-driven duplex pump for each bearing and the necessary high pressure piping. A separate pump for each bearing is desirable in order that the journals will be lifted in all bearings; if one pump supplies more than one bearing the chances are that the lifting of one journal will so reduce the pressure that it will be impossible to lift the remaining journals.

The cylinders are connected in pairs to a common pipe running to each bearing, the oil returning to the pump chamber by an overflow pipe. This arrangement is shown in Fig. 13. A high pressure check valve should be installed in each line and, as an additional precaution, it is recommended that a suitable check valve be installed near the bearing. This should be closed when the set is running in order to prevent a break in the oil film due to oil leakage. A hydraulic pressure gauge (reading to 1000 pounds per square inch) in each pressure line is a convenience.

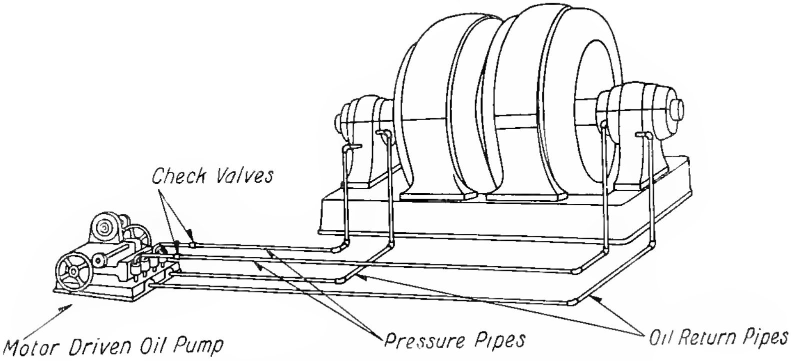


Fig. 13—Connections for Oil Pressure Starting System

Bearing Lubrication and Cooling—When the bearing diameter and speed are below certain limits it is possible to dissipate the generated heat by radiation and convection from the surface of the bearing housing. With larger bearings and higher speeds self-cooling is not sufficient and water-cooling is used. Bearings 14 inches in diameter, and larger, are usually provided with pipe connections for water circulation.

All bearings, regardless of size or speed are equipped with oil rings for lubrication. In larger bearings this method may be supplemented by a continuous flow of oil through the bearings maintained by gravity or pump. The larger bearings are provided with pipe connections to a station oiling system to be supplied as part of the station. Even when a station oiling system is installed the oil rings should be used as an additional factor of safety.

Fig. 14 shows a large bearing pedestal and the approximate location of the various pipe connections used.

Connections—Figs. 43 and 44 inclusive show typical wiring diagrams of frequency changer installations.

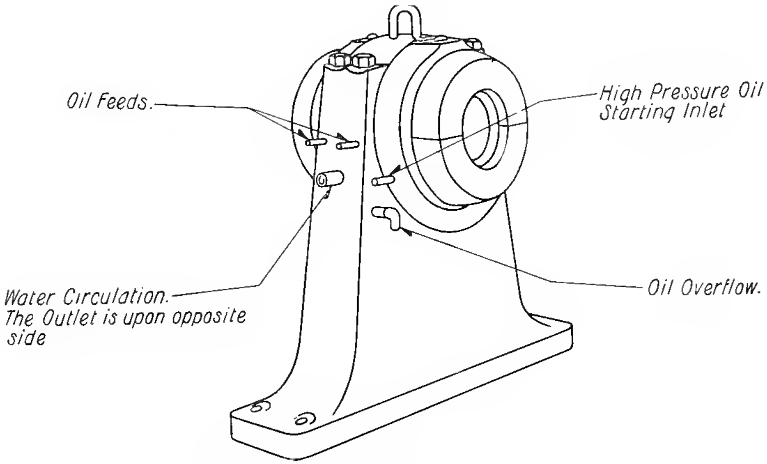

Oil Feeds.
High Pressure Oil Starting Inlet
Water Circulation. The Outlet is upon opposite side
Oil Overflow.

Fig. 14—Bearing Pedestal Showing Position of Oil and Water Piping

The wiring diagram for any particular installation should be obtained from the manufacturer of the switchboard.

All wiring should be installed in accordance with the rules of the National Board of Fire Underwriters.

High Tension Wiring—Exceptional precautions must be taken in running wires for high tension service. So far as possible all circuits should be out of normal reach and so placed as to minimize danger from mechanical injury or from contact with other electrical circuits.

All wiring should be exposed and rigidly supported on suitable insulators. Lead covered cables for high potentials are to be avoided unless absolutely necessary; when they are used, additional precautions must be taken to insure proper insulation.

Installation of Frequency Changers That Will Operate in Parallel—When two or more frequency changers are installed in the same station care must be taken that the main leads connecting both motor and generator to their respective busses are so connected as to secure the same direction of rotation in the several motors and to secure the same phase rotation in the several generators.

Direction of Rotation—The desired direction of rotation in the motors may be secured in the ways as already explained for motors of motor generators (see page 24). **The standard direction of rotation** of Westinghouse frequency changers is clockwise facing the collector side of the generator (or higher frequency machine when both machines are motors or generators).

General Phase Rotation—The standard phase rotation of Westinghouse generators with the above direction of rotation is from left to right hand terminals, facing the terminals.

If several sets in the same station are to be operated in parallel on the generator ends but not in parallel with another source of power it is only necessary to connect terminals similarly located to the same bus, assuming the direction of rotation is the same in all sets. As a precaution the phase rotation of the generators should be individually checked as described on page 24 before connecting the generator leads permanently to the busses.

If one or more frequency changers are to be operated in parallel with another source of power, the phase rotation of this source must be determined and that of the generators made to agree with it as described on page 24.

Phase Adjustment of Sets to be Operated in Parallel—Standard sets are built with the frame of the lower frequency machine supported in a cradle so that the frame can be rotated through a small angle. This is necessary in order that the relative phase of the motor and generator ends of the several sets may be identical. If this relation does not exist the several generators cannot be synchronized. This adjustment is only necessary at installation and it need be changed only in the event that additional sets are installed. The method of making this adjustment is described on page 62.

OPERATION OF MOTOR GENERATORS

Parallel Operation of Direct-Current Generators—The inherent regulation characteristics of the armature of a direct-current machine have much to do with its parallel operation with other machines. When two direct-current armatures are coupled in parallel and delivering load to the same external circuit it is necessary, in order to obtain stable conditions, for each armature to tend to "shirk" its load; that is, it must naturally tend to transfer load to the other machine. This tendency to shirk may be either in bad speed regulation due to the prime mover which drives the armature, or in the drooping voltage characteristics of the armature itself.

A drooping speed characteristic indirectly produces a drooping voltage characteristic in the armature and therefore both causes lead to the one characteristic, namely, drooping voltage, as the condition for stable parallel operation. This drooping voltage characteristic must be the inherent condition. In practice, the voltage at the armature terminals frequently rises with increase in load, but its rise is due to some external condition such as increased field strength and not to conditions in the armature itself.

Drooping Voltage Characteristics — Direct-current machines, without commutating-pole windings naturally give drooping voltage characteristics in the armature windings. If two such armatures are paralleled they tend to divide the load in a satisfactory manner, provided their prime movers regulate similarly in speed. If means are applied for giving a rising voltage characteristic to the machines, such as series coils in the field, then the armature terminals must be paralleled directly in order to maintain stability. If, for instance, the armatures by equalizer connections are not paralleled directly but the paralleling is done outside the series coils, then the operation will be unstable unless the machines still have drooping voltage characteristics. If they have rising characteristics, then parallel operation is impracticable. If either machine should take an excess of load its voltage would rise while that of the other machine would fall due to decreased load. This condition would naturally force the first machine to take still more load and the second one to take still less until the first machine actually fed current back through the other machine and it would be necessary to cut them apart to avoid injury. However, by paralleling the two armatures inside the series coils, that is, between the series coils and the armature terminals, this unstable condition is avoided for two reasons; first, the inherent drooping voltage characteristics of the armatures; and, second, the fact that the series coils are paralleled at both terminals, forcing them to take currents proportional to their resistances at all times and thus compounding both machines equally.

Rising Voltage Characteristics—If direct-current machines are so designed or operated as to give rising instead of drooping armature characteristics, then parallel operation is liable to be unstable. This condition could be obtained in non-commutating-pole machines by prime movers which tend to speed up with increasing load, thus producing rising voltage on the armature. Ordinarily, such speeding up of the prime mover would have to be rather large, as the normal drooping characteristics of the ordinary armature are fairly large; however, prime movers of this character are comparatively rare.

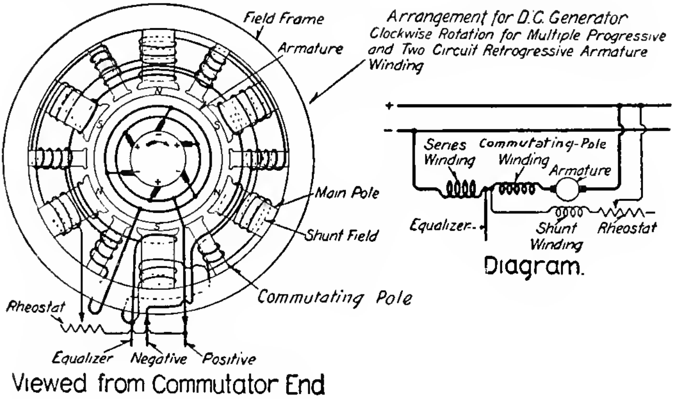


Fig. 15—Commutating-Pole Generator Diagram

A second condition which can give a rising voltage is not infrequently found in the commutating-pole type of direct-current machine. The commutating-pole winding is connected directly in opposition to the winding on the armature. The maximum magnetizing effect of the armature winding is found at the points on the armature corresponding to the coils which are being commutated.

The commutating pole is intended to be placed directly over these points and the winding normally has such a value that it not only neutralizes the magnetizing effect of the armature winding at these points, but it also sets up a small magnetic field in the opposite direction which assists in the commutation of the armature coil.

Effects of Commutating-Pole Positions—When this commutating-pole winding is placed directly over the commutating position of the armature winding it will have practically no effect on the armature characteristics. If, however, the commutating-pole winding is not placed over these positions it will have an effect on the voltage characteristics of the machine tending to either raise or lower the voltage, depending upon the position of the commutating pole with respect to the commutating position. The commutating points on the armature depend directly upon the brush position. If the brushes are rocked backward or forward from the point corresponding to the mid-position between the poles, then the position of the commutated armature coils moves backward or forward with the brushes.

Herein lies a possible trouble in parallel running, for the commutating points can be so shifted with respect to the commutating pole that the armature winding voltage characteristics can be made to rise instead of droop. As explained before, this is an unstable condition for parallel operation.

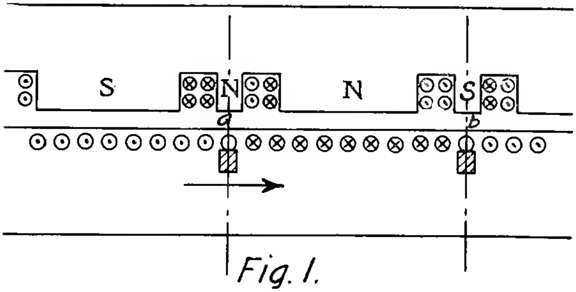


FIG. 16—TWO MAIN POLES AND TWO COMMUTATING POLES

Let Fig. 16 represent two main poles and two commutating poles, with the brushes set in a position corresponding to the middle point of the commutating pole. The polarity of any commutating pole and main poles is indicated in this figure. The polarity of any commutating pole when the machine is running as a generator is always the same as the polarity of the main pole immediately in front of it. When the brush is placed in a position corresponding to an exact intermediate point in the commutating pole it is evident that the armature coils lying between two commutating points, that is, the winding between a and **b** in Fig. 16 are acted upon by induction from the main pole and by half the induction from the commutating poles adjacent to the main pole. However, as these two commutating poles are of opposite polarity and the induction is the same from each, it is evident that they have equal and opposite effects on the armature winding between **a** and **b** and therefore do not affect its voltage.

Back Lead—In Fig. 17 the brushes are given a slight back lead so that the commutation is under the traveling magnetic flux from the commutating poles. It is not evident that between a and b the induction is from the main pole and from one commutating pole principally. With the back lead at the brushes, the commutating pole is the one immediately behind the main pole and therefore of the same polarity. This commutating pole, therefore becomes a magnetizing pole and adds to the electromotive force generated between a and b. As the strength of this commutating pole is zero at no load and rises with load, it is evident that it tends to give an increased voltage between a and b as the load increases and tends to produce a rising voltage characteristic instead of a drooping one.

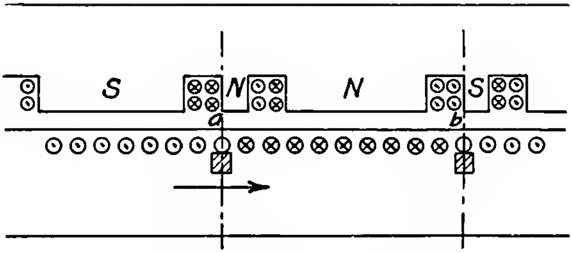


Fig. 17—Brushes Given a Slight Back Lead

As stated before, the number of ampere-turns in the commutating pole is considerably greater than in the armature. but ordinarily the effect of these ampere-turns is almost neutralized by the oposing effect of the armature winding. However, with the back lead, as indicated in Fig. 17, the opposing effect of the armature winding is shifted to one side of the commutating pole and thus the commutating pole ampere-turns become more effective in actually magnetizing the armature, but become less effective in creating a commutating field for the coils which are now being reversed by the brushes. On account of this less effective field it may be necessary in practice to still further increase the ampere-turns on the commutating pole in order to bring the trailing magnetic fringe up to a suitable value for producing proper commutation.

It is evident that this increased number of ampere-turns on the commutating pole increases the induction under other parts of the commutating pole as well as under the trailing tip, and this increase under the other parts of the pole still further increases the voltage between a and b.

With a back lead, therefore, the commutating pole may have the same effect as the series winding on the main field;

that is, it may compound the machine so that the voltage at the terminals is rising instead of falling, even without any true series winding on the main poles. The machine therefore becomes an equivalent of a compound-wound machine and if there is no equalizer between the interpole winding and the armature terminal, the generator may be unstable when paralleled with other machines.

Forward Lead—Take the case, next, where the brushes are given a forward lead, as shown in Fig. 18. Comparing this with Fig. 17, by the same reasoning it is evident that the commutating pole is now opposing the effect of the main pole, in the winding between **a** and **b**. The interpole therefore tends to produce a drooping voltage characteristic and has just the opposite effect to the series winding. In this position of the brushes the commutating winding tends to give good characteristics for parallel operation, but as the effect of the commutating pole is in opposition to the main pole it is evident that more series winding is required on the main field in order to over-compound the machine as a whole. Also, with the brushes in this position the commutating pole is not as effective in producing good commutation and therefore more ampere-turns are required on the commutating winding. Therefore, both winding must be increased when the brushes are given this forward position but parallel operation should be stable.

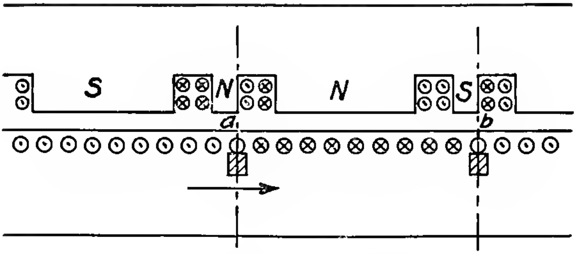


FIG. 18—BRUSHES GIVEN A SLIGHT FORWARD LEAD

Correct Brush Position—It is evident, therefore, from the above considerations that for best results the brushes should be so set that the true point of commutation comes midway under the commutating pole. If this position is found exactly, then the commutating pole should have practically no effect on the voltage characteristics of the armature, and parallel operation with other generators should be practicable. A very slight forward lead is favorable to paralleling, but lessens the compounding.

As a back lead at the brushes, when the machine is acting as a generator, tends to improve the compounding and lessen the series winding required on the main field, it might be suggested that this gives a cheaper and more efficient machine and that therefore this arrangement should be used, with some means added for overcoming the unstable conditions of paralleling. One means proposed for this is an additional equalizer connected between the commutating poles and the armature terminals. This has been used in one or two instances, but in principle the arrangement is inherently wrong. When the commutating-pole windings are paralleled, then the currents in them must divide according to their resistance.

This condition would not be objectionable provided the armature currents also varied in the same proportion. With slow changes in load this condition might be obtained. However, there are conditions of operation where the armature currents will not rise and fall in proportion and therefore the commutating-pole windings, with this arrangement, would not always have the right value to produce the desired commutating fields. Each armature should be connected directly in series with its own commutating poles and the currents in the two should rise and fall together for best results. This condition will not be obtained when an equalizer is connected between the armatures and commutating poles and this solution of the problem should therefore be avoided in general.

With **correct brush position** there should be no difficulty in paralleling commutating-pole generators with each other or with generators without commutating poles. **The equalizer should always be connected between the series winding and the commutating-pole winding,** the commutating-pole winding being treated as part of the armature circuit.

Adjustment of Load Division and of the Equalizer Circuit—With two compound-wound generators operating in parallel, one of which takes less than its proper share of the load, the division of load can be changed by the following adjustments.

(a) The shunt field rheostats may be adjusted to give better **average** division. If one generator compounds less than another and it is desired to maintain the higher full-load voltage the average load of the former generator can be increased by increasing the shunt field excitation.

(b) The shunts on the series-field winding can be adjusted, decreasing the resistance of the shunt on the overloaded generator, if possible, or increasing the resistance of the shunt on the underloaded generator. It should be borne in mind, however, that changing the ampere-turns in the series field by changing the shunt resistance also changes the resistance of the complete field circuit. This change in resistance must be compensated for by a corresponding change in resistance in another part of the series-field circuit so that the resistance of the total circuit remains unchanged. From another standpoint, a shunt on one series field may be considered a shunt on both series fields, the effect varying only by reason of the resistance of the leads and busses being added to one shunt circuit and not to the other.

(c) If the relative ampere-turns are correct, but the series field resistances are differently proportioned, the resistance of the leads between the series field and equalizer bus can be changed to compensate for a difference in the series-field resistances. The resistance in the series circuit of the generator taking more than its share of the load should be increased. This adjustment varies the resistance of one series field without introducing a third parallel circuit between the equalizer and main bus, and for this reason the adjustment is less complicated than in (b).

In making the above adjustment it is advisable to make the changes systematically.

The several generators should be operated separately and the voltages at all loads should be made as nearly equal as possible by adjustments of the shunt-field rheostat and by changing the series-field current by means of shunts across the series field. It may be advisable to operate the several generators with different no-load voltages in order to obtain a better average agreement between the several voltage regulation curves. It is not so important that the voltages at partial loads agree as it is at full load and overloads. At partial loads the load division may depart from the correct division without overloading the generator that takes the greater share of the load.

When the several regulation curves have been made to agree as nearly as possible, then the resistances of the several equalizer circuits should be checked and changed, when necessary, by changing the resistance of the equalizer leads to make the resistances inversely proportional to the generator ratings. For example, if a 500-kilowatt generator and a 1500-kilowatt generator are operated in parallel, the resistance of the series-field circuit (including a shunt if used) the main lead from the series field to main bus, and the equalizer leads should be in the case of the 1500-kilowatt generator one-third of the resistance of the corresponding circuit of the 500-kilowatt generator.

Power Factor—When any alternating current and its electromotive force are in the same phase, i. e., rise and fall in strength exactly together, the power in the circuit is the product of the current and the electromotive force. But when the current lags behind the electromotive force, as in the case of a current flowing to an unloaded induction motor or transformer, or under excited synchronous motor or when the current is in advance of or leads the electromotive force, as in the case of the current to an over-excited synchronous motor, the power in the circuit is less than the product of the amperes and volts. In cases where the currents lead or lag behind the electromotive force, the actual power in the circuit will be equal to a certain definite per cent of the power that the circuit would represent were the current and electromotive force in phase This per cent is called the "power factor" of the circuit. It is the ratio between the true power and the "apparent" power. Its value depends upon the amount the current lags behind or leads the electromotive force.

Excitation of Synchronous Motors—The excitation of a synchronous motor is not necessarily supplied entirely by the field winding. The voltage generated by the synchronous motor (the counter electromotive force) is determined by the line voltage. If the field excitation is such that, with the motor operating alone as a generator, this value of counter electromotive force would not be generated, then an exciting current will flow in the armature winding (when the motor is connected to the alternating current lines) to add to or subtract from the field excitation, as the case may require. This armature exciting current is the so-called leading or lagging component of the motor current and bears a 90 degree relation to the motor counter electromotive force. If the field current is just sufficient to generate the required motor counter electromotive force, then no exciting current is required in the armature and the entire motor current is used in driving the motor, that is, represents actual power and the power factor of the motor is 100 per cent. If the field current gives less than this required excitation, then the armature must supply the deficiency and a current flows in the armature circuit that is magnetizing or "leading" with respect to the motor circuit but is demagnetizing or "lagging" with respect to the supply circuit. **Under excitation** in the synchronous motor is **detrimental** to the power factor of the usual supply circuit. If, on the other hand, the field excitation is increased to give more than the required excitation, then a demagnetizing current will flow in the armature that is magnetizing or "leading" with respect to the supply circuit. **Over Excitation** in the synchronous motor will raise the power factor of the supply circuit that previously had a lagging power factor.

Power Factor Correction by Synchronous Motors — The synchronous motor is frequently made larger than necessary to drive the direct-current generator in order that it may be over excited and made to supply leading current to the alternating-current system. If a motor is rated at 80 per cent power factor, for example, it will drive the generator carrying its rated load and in addition supply 60 per cent of the rated kva. of the motor as leading kva. to the alternating-current system. If the set is rated at 1000 kilowatts the motor will have an input of $\frac{\text{Efficiency x P. F.}}{1000}$ or, in round numbers. $\frac{1000}{.90 \text{ x } .80}$ or 1400 kva. (nearly). It will then supply .60 x 1400 or 840 kva. as leading current to the alternating-current system.

If the synchronous motor is under excited it will take lagging current from the alternating-current system and will **reduce** the system power factor. The reduction in power factor may be much greater than due to an equivalent induction motor if the field current adjustment is much reduced so that the correct field current adjustment is very important. A synchronous motor-driven set may be installed to improve the power factor and through careless operation may have just the opposite effect.

The effect of leading current in raising the power factor of the alternating-current system can be readily calculated if the following relations are kept in mind.

The total or combined alternating current or kva. may be considered as made up of two currents, or kva's; one in phase with the line voltage representing energy and available for doing mechanical work; and a second, bearing a 90-degree phase relation to the voltage which does not represent mechanical energy but which either increases or decreases the existing reactive* current of the system.

The energy and reactive components of the current or kva. in several branch circuits forming part of a common system may be directly added or subtracted and the combined current determined by combining the total energy and total reactive components.

An example will serve to show the application of these principles.

Problem—Assume that an existing system has a load of 5000 kva. with a power factor of 75 per cent. A 1111-kilowatt 80 per cent leading power factor motor generator is added to the system. What will be the combined kva. and power factor?

Solution—The energy and reactive components of the existing load are shown by the right angled triangle Fig. 21.

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*The word reactive is used where formerly the word "wattless" applied. This component of the current while it does no external mechanical work is "watted" to the extent that it heats the conductors carrying it. Therefore the word, "wattless" is really a misnomer, and is being replaced by a more suitable term, the reactive component.

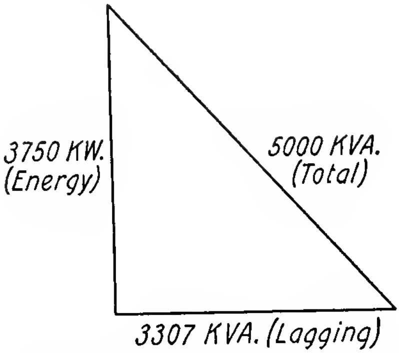

FIG. 19—DIAGRAM SHOWING RELATION BETWEEN KVA., KW., AND REACTIVE COMPONENT OF ORIGINAL LOAD

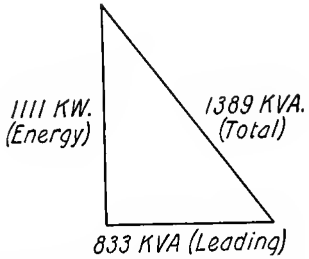

FIG. 20—DIAGRAM SHOWING RELATION BETWEEN KVA., KW., AND REACTIVE COMPONENT OF ADDED MOTOR-GENERATOR LOAD

The energy component is determined by multiplying the total kva. by the power factor (5000 x .75). If the energy component is known instead of the total kva. then the latter can be found by **dividing** the energy component by the power factor. The third side of the triangle can then be calculated by squaring the two known sides and taking the square-root of their difference, thus:

$$\begin{aligned} 50000^2 &= 25000000 \\ 3750^2 &= 14062500 \\ \hline \sqrt{10937500} &= 3307 \end{aligned}$$

Or, if a table of sines and cosines is available the third side can be found by multiplying the total kva. by the cosine of the angle whose sine is the power factor. Thus the angle whose sine is .75 is 48°-35½′ and the cosine of this angle is .6615. This multiplied by 5000 is 3307.

The triangle for the added load should be similarly calculated. This is shown in Fig. 20.

The triangle representing the combined load is obtained by adding the two energy components and subtracting the two reactive components (since one is lagging and one is leading). This is shown in Fig. 21.

In this case the third side of the triangle (the total kva). is obtained by taking the square root of the **sum** of the squares of the two known sides. The power factor of the combined load is 4861 divided by 5454 or 89.1 per cent.

The improvement in power factor due to the addition of a 100 per cent power factor load, such as a motor generator,

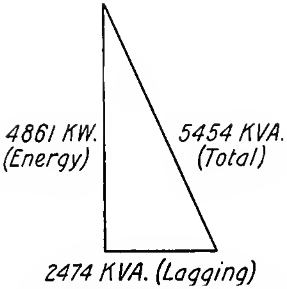

FIG. 21—DIAGRAM SHOWING RESULTANT KVA., KW., AND REACTIVE COMPONENT AFTER ADDING LEADING POWER FACTOR

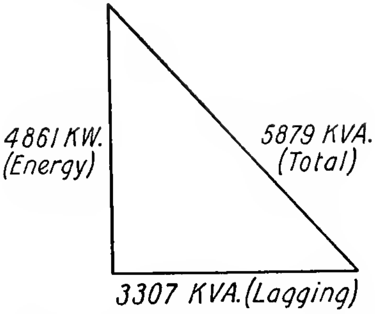

FIG. 22—DIAGRAM SHOWING RESULTANT KVA., KW., AND REACTIVE COMPONENT AFTER ADDING 100 PER CENT POWER FACTOR LOAD

without increased capacity in the synchronous motor will be evident from a consideration of the above example. The combined load on this basis is shown by the triangle Fig. 22. The power factor with this combined load is 4861 divided by 5879 or 82.7 per cent. By addition of this 100 per cent power factor load the power factor was increased nearly 8 per cent, over the original of 75 per cent.

Circuit Breaker Protection on Reverse Direct Current— Whenever there is a source of direct current in parallel with a generator that is also independent of the high-tension alternating-current feeder serving the motor of the set a relay should be provided that will open the direct-current breaker in case the direct current reverses. Such an independent source of direct current may be a direct-current generator, a storage battery, or a synchronous converter, usually in other substations, fed from the same or different generators, but connected in parallel through continuous feeder or trolley circuits.

Setting of Circuit Breakers in Railway Substations — In some railway systems the conditions are such that short-circuits occur on the feeder or trolley circuits that are so severe that the generators flash and the arc holds until the generator "kills" itself. In such cases the severity of the short-circuits should be reduced by the insertion of resistance in the affected feeders as described on page 22.

In this connection it should be remembered that in the case of severe short-circuit the current increases rapidly compared with the speed at which the breaker is set. In the case of a short-circuit immediately outside the substation the current may easily reach five to ten times the normal rated current of the generator assuming the ordinary types of carbon circuit breaker is used and this current value will be practically independent of the circuit breaker setting.

Some generators will satisfactorily commutate very large momentary currents, provided the machine circuit breaker does not open; while they will flash with no greater currents, if the machine circuit breaker does open. In such cases it is advisable to set the generator circuit breakers so that they will open only in the event of very severe short-circuits.

Protection against ordinary overloads should be provided by lower setting of feeder breakers. The selective action between the feeder breakers and generator breaker may be obtained either by a different current setting or in time setting (if means for time adjustment are provided).

OPERATING INSTRUCTIONS
MOTOR GENERATORS

General Instructions

Before starting a motor generator the following routine should be regularly observed.

(1) The brushes of the generator and motor should be (if synchronous) examined to see that they move freely in their holders.

(2) See that no loose material, such as a bolt or tool, is near enough to the moving or live parts of the set to cause damage.

(3) See that the speed limit device is in operating condition.

(4) See that all switches in both motor and generator circuits are open.

(5) Examine the bearing housings to see that there is oil in the wells and that the oil rings turn freely.

(6) When the set has been started, examine the oil rings to see that they are revolving properly, and examine both motor and generator brushes to see that they are properly seated on the collector on commutator and are not sparking.

Starting Instructions

I—Synchronous-Motor-Driven Set, A. C. Self-Starting— For this method of starting, one starting voltage is ordinarily used. This may be supplied from auto-transformers or from taps on the step-down transformers, when these are used, on account of high line voltage. With auto-transformers a starter having suitable contacts for connecting them to the line and to the motor for starting and for connecting the motor directly to the line for running, or the equivalent in a combination of circuit-breakers, is used.

With step-down transformers a plain double-throw circuit-breaker or the equivalent in two single-throw breakers having handles interlocked, is used.

The motor field circuit is closed during starting to prevent the generation of high voltage in the field winding.

If the motor field is excited from a source external to the motor generator, it is necessary to have a two pole double throw field discharge switch which in the lower position short circuits the field upon itself through the field rheostat.

If the motor field is excited from a direct-connected exciter or from the direct-current generator driven by the motor no field switch is necessary as the motor field is practically short circuited upon itself through the motor field rheostat and the armature of the exciting generator. If a single throw field switch has been provided it must be closed before the motor is started.

In starting synchronous-motor-generator sets, the motor will pull into step when connected to the starting voltage. The motor should be excited while connected to this low voltage and if the motor is over excited there will be a smaller current rush than otherwise when the starter is thrown from the starting to the running position and full line voltage applied. In starting a set by this method, proceed as follows:

(1) With all switches open, close the motor field switch in the starting position.

(2) If step-down transformers are employed, close the oil circuit-breaker on the high-tension side.

(3) Close the motor starter in the starting position. If the motor revolves in the wrong direction, shut down, and change the alternating-current cable connections as described (see page 22) and proceed as before.

The set should come up to synchronous speed on the starting voltage in from 30 to 60 seconds and lock into step.

(4) Throw the field switch to the running position thereby exciting the motor field. Adjust the field rheostat to increase the field current to a value above the value required for 100 per cent power factor. Determine by trial the value of field current that results in the smallest line current when the main switch is thrown over to the running position. If the motor is excited from an exciter or the generator driven by the motor it is only necessary to adjust the field current.

(5) Throw the exciter over to the running position as quickly as possible as the motor is momentarily disconnected from the line during this operation.

(6) Adjust the motor field rheostat to give the desired power factor at full load.

If driving a direct-current generator proceed as follows:

(1) For Two-Wire Service—Close the positive direct-current circuit-breaker; close the equalizer and negative switches; adjust the direct-current voltage and when correct for connecting the generator to its load, close the positive knife switch.

(2) For Three-Wire Service—Close the direct-current circuit-breaker; close the negative equalizer and main switch; adjust the direct-current voltage and when correct for connecting the generator to its load, close the positive equalizer and main switch.

II—Induction Motor-Driven Set, A.C. Self-Starting—The operation of starting is the same as with the self-starting synchronous motor except that it is simplified by the absence of motor field windings.

(1) With all switches open, if step-down transformers are employed, close the oil circuit-breaker on the high tension side.

(2) Close the motor starter in the starting position. If rotor revolves in the wrong direction, shut down, and change the alternating-current cable connections as described (see page 24) and proceed as before.

(3) When the motor is up to speed (requires from 30 to 60 seconds) throw the starter over to the running position as quickly as possible as the motor is momentarily disconnected from the line during this operation.

(4) Proceed as under (I) for connecting the direct-current generator to its load.

III—Synchronous Motor-Driven Set, Direct-Current Self Starting—With this method of starting, the set is started by the direct-current generator operating as a motor and the alternating-current motor is synchronized with the supply system. Refer to page 54 for information on synchronizing. In starting a set proceed as follows:

(1) For two-wire generators having the negative switch on switchboard:

(a) Insert the voltmeter plug for the direct-current voltmeter and turn the field rheostat to cut out the resistance so that the machine will not be started with a weak field.

(b) Close the series-field short-circuiting switch, if supplied.

(c) Close the positive circuit-breaker after connecting its low voltage coil with resistance to the bus-bars by means of the two-pole double-throw switch. The coil and resistance is connected to the machine when the set is started from the alternating-current side. (The two-pole double-throw switch is furnished only when the set may be started from either the alternating-current or the direct-current side.)

(d) Close the positive switch.

(e) Start the set by closing the direct-current starting switch, cutting out the starting resistance slowly. If the machine rotates in the wrong direction, reverse either field or armature connections. Check polarity of windings before putting machine into service if any change in connections has been made.

(f) Adjust the speed of the set to synchronous speed by means of the generator field rheostat.

(g) Close motor field switch, if any, and adjust the motor field current by means of the field rheostat to give desired voltage at the motor terminals.

(h) Phase out the synchronous motor as described on page 24.

(i) Insert the synchronizing plug when the speed and voltage of the motor are approximately correct. When the lamps or synchroscope indicate synchronism close the alternating-current circuit-breaker, connecting the motor to the line.

(j) Adjust the generator field rheostat so that the machine will operate as a generator.

(k) Close the negative switch and open the starting switch.

(l) Open the series-field short-circuiting switch, if any.

(m) Close the equalizer switch, if any.

(n) Adjust motor field for correct setting for desired power factor at full load.

(2) For railway generators having only the positive switch on switchboard:

In this case the starting switch is connected in shunt with the positive switch and the double-throw switch for transferring the low voltage coil circuit is single pole only.

The procedure is the same as for (1) except that the negative switch is closed before operation (c), operation (d) is omitted, and for (k) the positive switch is closed.

(3) For three-wire generators started from the main bus-bars:

In this case the starting switch is connected between the bus side of the negative main switch and the machine side of the negative equalizer switch. The procedure is the same as for (1) except that for (c) the breaker will be two or four pole and all poles should be closed. The single pole neutral switch must be open before closing the positive main and equalizer switch. The neutral switch should be closed again after the negative main and equalizer switch has been closed.

(4) For three-wire generators started from the equalizer bus-bars:

In this case the starting switch is connected in shunt with equalizer pole of the two-pole negative switch and the positive main and equalizer leads have two single-pole switches instead of one two-pole switch. The procedure is the same as for (3) except that the positive main switch is not closed until after the negative main and the equalizer switch have been closed.

IV—Wound Secondary Induction Motor Starting Without Current in the Synchronous Motor Armature—(1) With all switches open, close the oil circuit-breaker on the high tension side of the transformer, if any.

(2) Start the set by closing the circuit-breaker in the primary circuit and the switches or controller in the secondary circuit of the induction motor.

In case the machine rotates in the wrong direction reverse starting motor leads as described (see page 24). The set will be brought up slightly above synchronous speed.

(3) Close motor field switch, if any, and adjust the motor field current by means of the field rheostat to give approximately line voltage at the motor terminals.

(4) Phase out the synchronous motor as described on page 24.

(5) Insert the synchronizing plug when the speed and voltage of the synchronous motor are approximately correct.

(6) Trip the primary circuit-breaker to the induction motor, which also opens the secondary switches. Allow the speed of the set to decrease and when the lamps or synchroscope indicate synchronism, close the alternating-current circuit-breaker, connecting the motor to the line.

(7) Adjust the motor field rheostat to give the desired power factor at full load.

(8) If driving a direct-current generator proceed as under (I) for connecting the generator to its load.

V—Squirrel Cage Induction Motor Starting With the Starting Motor Windings in Series With the Synchronous Motor Armature Windings—(1) With all switches open, close the oil circuit-breaker on the high tension side of the transformer, if any.

(2) Close the motor field switch, if any.

(3) Start the set by closing the circuit-breaker in the starting motor circuit thus energizing the synchronous motor windings. The main motor and starting motor windings must have the same phase rotation so that both windings will tend to rotate the revolving part in the same direction. If the armature revolves in the wrong direction reverse as described (see page 24).

The motor should come up to speed and lock into step as with alternating-current self-starting.

(4) Close the oil circuit-breaker in the synchronous mo-

tor circuit thus short circuiting the starting motor and then open the breaker in the starting motor circuit.

(5) Adjust motor field to give desired power factor at full load.

(6) If driving a direct current generator proceed as under (I) for connecting the generator to its load.

Excitation of Direct-Current Generators—When starting up, a generator may fail to excite itself. This may occur even when the generator operated perfectly during the preceding run. It will generally be found that this trouble is caused by a loose connection or break in the field circuit, by poor contact at the brushes due to a dirty commutator or perhaps to a fault in the rheostat, or incorrect position of brushes. Examine all connections; try a temporarily increased pressure on the brushes; look for a broken or burnt out resistance coil in the rheostat. An open-circuit in the field winding may sometimes be traced with the aid of a magneto; but this is not an infallible test as some magnetos will not ring through a circuit of such high resistance, even though it be intact. If no open circuit is found in the rheostat or in the field winding, the trouble is probably in the armature. But if it be found that nothing is wrong with the connections or the winding it may be necessary to excite the field from another generator or some other outside source. Calling the generator we desire to excite No. 1, and the other machine from which current is to be drawn, No. 2 the following procedure should be followed. Open all switches and remove all brushes from generator No. 1 connect the positive brush holder of generator No. 1 with the positive brush holder of generator No. 2; also connect the negative holders of the machine together (it is desirable to complete the circuit through a switch having a fuse of about 5 amperes capacity in series). Close the switch. If the shunt winding of generator No. 1 is all right, its field will show considerable magnetism. If possible reduce the voltage of generator No. 2 before opening the exciting circuit; then break the connections. If this cannot be done, throw in all the rheostat resistance of generator No. 1; then open the switch very slowly, lengthening out the arc which will be formed until it breaks.

A very simple means for getting a compound wound machine to pick up is to short-circuit it through a fuse having approximately the current capacity of the generator. If sufficient current to melt this fuse is not generated, it is evident that there is something wrong with the armature either a short-circuit or an open circuit. If, however, the fuse has blown, make one more attempt to get the machine to excite itself. If it does not pick up, it is evident that something is wrong with the shunt winding or connections.

If a new machine refuses to excite and the connections seem to be all right, reverse the connections, i. e., connect the wire which leads from the positive brush to the negative brush and the wire which leads from the negative brush to the positive brush. If this change of connection does no good, change back and locate the fault as previously advised.

Emergency Instructions—(1) When direct-current generators flash over or the breakers come out from excessive current, it is always wise to note the direct-current voltmeter before throwing in on the line again, as these troubles very frequently cause a reversal of polarity in the fields, making them build up in the opposite direction. If this should be the case, it will be necessary to reverse polarity.

(2) When the alternating-current power goes off for any reason, shut down the set at once, opening all switches.

(3) When the alternating-current breakers come out, open the direct-current breaker (if not tripped out automatically) and the switches, and then proceed to start as in first starting.

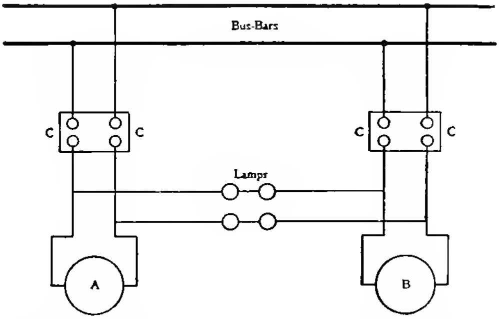

Fig. 23—Connections for Synchronizing Low-Voltage Single-Phase Generators

(4) When a direct-current generator flashes over and is thrown out of circuit, it is best if possible to shut down for a moment and examine the commutator and brushes and clean up any burrs which may have been caused. If this is not possible, the commutator may be cleaned, by exercising great care, after the set has been put in service.

CAUTION

Leave all the switches open when the set is not operating.

When the shunt-field circuit of a generator or motor is excited, never open it quickly unless a path for the inductive discharge is provided. The circuit can be opened slowly, if de-

sired, the arc at the opening serving to reduce the field current gradually. Do not permit any part of the body to bridge this opening, or a serious shock will be received; better use but one hand, keeping all other parts of the body clear of the circuit.

Always follow a fixed regular order in closing and opening switches unless there are special reasons for departing from this order. A routine method will aid in avoiding mistakes. Close switches carefully, keeping firm hold of the handles until completely closed.

Keep small pieces of iron and bolts and tools away from the frame. Any such fragment attached to the pole of a field magnet may jam between the armature and pole and cause serious damage.

OPERATION OF FREQUENCY CHANGER SETS

Synchronizing A.C. Generators—The fundamental condition necessary in order that synchronous apparatus may be connected to a system already in operation is that the electromotive forces of the incoming machine and of the system to which it is connected shall be approximately the same at each instant. This requires that the frequencies be the same; that the two voltages be equal, as indicated by a voltmeter, and that the two voltages be in phase.

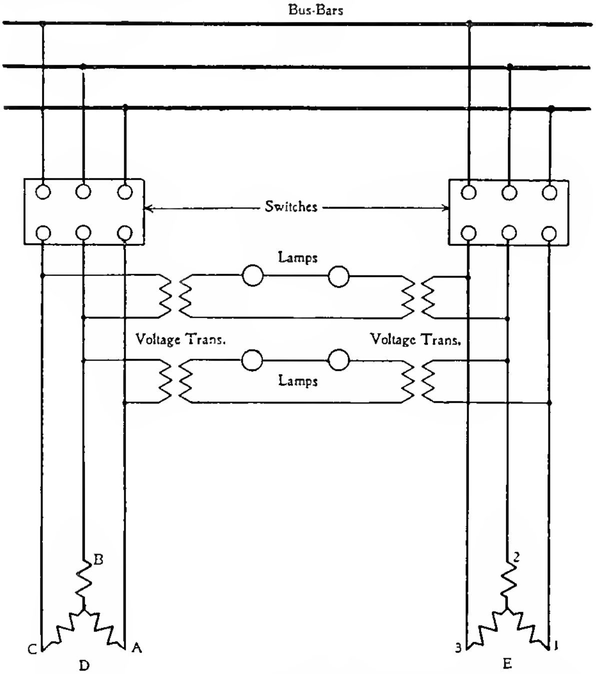

Fig. 24—Connections for Synchronizing Three-Phase Generators

The elementary principle employed in determining when generators are at the same frequency and in phase is illustrated by Fig. 24 in which A and B represent two single-phase generators, the leads of which are connected to the bus-bars by switches C and two series of incandescent lamps which are connected as shown. As the electromotive forces change from the condition of phase coincidence to that of phase opposition, the flow of current through the lamps varies from a minimum to a maximum.

When the electromotive forces of the two machines are exactly equal and in phase, the current through the lamps is zero.

As the difference in phase increases, the lamps light up and increase to a maximum brilliancy when corresponding phases are in exact opposition. From this condition the lamps will decrease in brilliancy until completely dark, indicating that the machines are again in phase. The rate of pulsation of the lamps depends upon the difference in frequency, i. e., upon the relative speeds of the machines.

When the voltage of the system is too high for any of the synchronizing apparatus it is usual to place voltage transformers between the main circuits and the synchronizing circuits to reduce the voltage at the switchboard to safe limits, as shown in Fig. 24.

In order to determine whether the lamps will be bright or dark for a given synchronizing connection when the machines are in phase, disconnect the main leads of the first generator at the generator and throw in the main switches of both generators with full voltage on the second generator. Since both machine circuits are then connected to one machine, the lamp indication will be the same as when the main or paralleling switches are open and both machines are in phase. If the lamps burn brightly and it is desired that they be dark for an indication of synchronism the connections of one of the voltage transformer primaries or one of the secondaries should be reversed. **Dark lamps as an indication of synchronism are recommended.** The lamps should be adapted for the highest voltage which they will receive, i. e., double the normal voltage.

Phase Rotation—In the case of polyphase machines, it is not only necessary that one phase be in synchronism with one phase of another generator but the sequence of maximum values of voltage in the several phases must be the same. The "phase rotation" must therefore be checked. The necessary connections for two three-phase generators are shown in Fig. 24.

Connect the generators temporarily to their switches so that the phases of D will be in parallel with those of E. For example connect phase A-B to 1-2; phase B-C to 2-3; and phase C-A to 3-1. Connect synchronizing apparatus in any two phases, as phase $\left\{\begin{matrix}\text{A-B}\\ \text{1-2}\end{matrix}\right.$ and phase $\left\{\begin{matrix}\text{2-3}\\ \text{B-C}\end{matrix}\right.$ Test out the synchronizing connections with machine D running at normal speed and voltage, the leads disconnected from E at the generator, and the paralleling switches closed. Having changed the synchronizing connections, if necessary, so that both sets of lamps will be the same when indicating synchronism, open the paralleling switches, re-connect the leads of machine E and bring it up to normal speed and voltage. Then observe the two sets of synchronizing lamps. If their pulsations come together, i. e., if both sets are dark and both are bright at the same time, the phase rotation of the two generators are the same, and the connections are correct for paralleling the generators when the lamps are dark. If, however, the pulsations of the lamps alternate, i. e., if one is dark when the other is bright, reverse any two leads of one machine and test out the synchronizing connections again, changing them if necessary so that they are the same when indicating synchronism. The lamps will now be found to pulsate together and the generators may be thrown in parallel at the proper indication. Synchronizing apparatus in one phase only is sufficient for paralleling the generators after the first time.

The procedure in synchronizing a generator with an existing power system is the same, the phase rotation of the generator being changed. if necessary, to agree with that of the system.

The paralleling of two-phase generators is accomplished in a similar manner. In case of incorrect rotation the two leads belonging to either phase must be reversed instead of any two leads.

The standard winding of Westinghouse two-phase armatures is of the open type with separate circuits. The four leads are marked A-1. B-1. A-2. B-2. in regular consecutive order around the armature. The two terminals A-1, A-2, constitute one of the main circuits or phases and B-1, B-2, the second main circuit or phase which will give the full electromotive force of the machine.

Synchroscope—A synchroscope is an instrument that indicates the difference in phase between two electromotive forces at every instant. By its aid the operator can see whether the incoming machine is running fast or slow, what the difference in speed is, and the exact instant when it is in synchronism. These conditions cannot be observed with certainty by the use of lamps alone and it is usual practice for large machines to have both synchroscope and lamps.

The synchroscope has a pointer which shows the phase angle between the incoming and running machines. This angle is always equal to the angle between the pointer and the vertical position marked on the dial of the instrument. When the frequencies of the two machines are equal the pointer stops at some position on the scale and when the machines are in phase the pointer coincides with the marker at the top of the scale.

In order to check the synchroscope connections, proceed in the same manner as previously described for determining whether lamps will be bright or dark for a given synchronizing connection. If the synchroscope pointer stops at the bottom, reverse the leads at the upper terminals. If it stops in the same position the connections to the upper terminals are made to the wrong phase.

Synchronizing Two Frequency Changers—In order that this explanation may be simplified, it will be assumed that the armature windings of the various machines are identical in location and sequence of terminal coils. Then the position, at some chosen time, of a pole of the rotating field (with respect to a group of armature coils covering one pole switch) represents the phase of a voltage generated in the motor or generator winding; accordingly, in the following explanation the "position of the rotor pole," or, "polar position" will signify the voltage phase. Thus, if two synchronous motors are operating from the same supply system without load the polar positions of the two motors will be the same. Likewise, before two generators can be synchronized, the polar positions of the two rotors must be made the same.

A distinction will also be made between "polar position" and "rotor position;" the former will mean the phase of the generator voltage, while "rotor position" will mean the mechanical position of the rotor without reference to magnetic or electrical conditions. This distinction may be illustrated in the following way: If a synchronous motor is in synchronism with the generator and is then caused to slip two poles its polar position will not have been changed while its rotor position will have been changed.

In synchronizing two engine-driven generators, it is not difficult to bring the two rotors into the same polar position, since the two rotors may be independently controlled in speed and the relative polar positions are continuously changing. Moreover, the two generators will have the same polar positions (that is, will be in synchronism) when any pole of one generator has the same position as any pole of the same polarity of the other generator. There are as many positions of the rotor that are correct for synchronizing as there are poles of the same polarity on the incoming generator.

When a synchronous motor driven frequency changer is to be synchronized with another similar set, the same general principals apply, but the rigid mechanical connection between the poles of the motor and the poles of the generator considerably reduces the number of correct rotor positions of the motor In the case of two sets, the two motors must have the same polar positions and at the same time the two generators must have the same polar positions. Referring to Fig. 26, which represents a 4-pole-6-pole set, if the two motors are connected to the same position, then the generator poles N_1 in both sets will have the same position and the sets will be in synchronism on

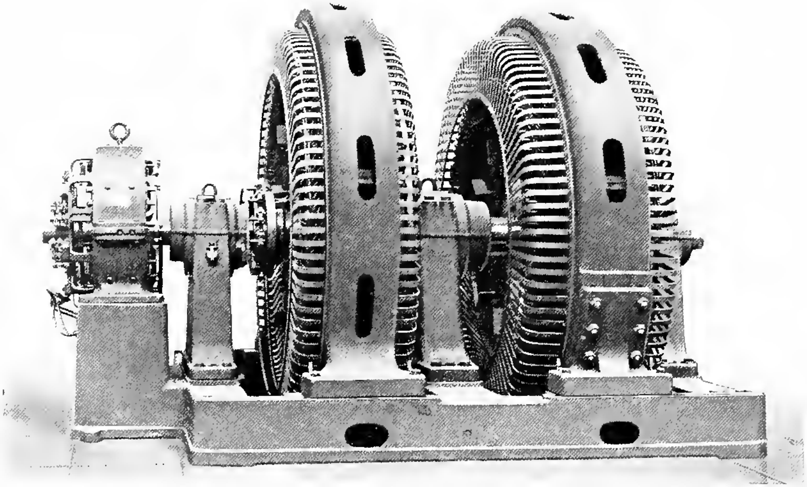

FIG. 25—FREQUENCY CHANGER

Showing motor frame mounted in cradle for rotation. The usual commercial range of this frame shifting device is about four mechanical degrees; on a ten-pole motor this corresponds to 20 electrical degrees.

both ends. If, however, the two motors are connected to the supply circuit so that pole N_1 in one motor has the same position as pole N_2 in the other motor (which is a possibility considering the motors alone) then pole N_1 in one generator will have the same position as pole S_2 in the generator and the two generators will be 180 degrees out of phase at the same time the two motors are in phase. If the two motors are considered alone, there are two correct rotor positions; if the two generators are considered alone, there are three correct rotor positions; but if the motor and generator are tied rigidly together, as in a frequency changer, there is only one correct rotor position for the incoming motor. For the sake of brevity "synchronizing position" will be used to denote that rotor position of the incoming motor in which both motor polar positions will be the same and both generator polar positions will be the same. In general, the number of synchronizing positions in any pair of sets is equal to the greatest common divisor of the number of possible synchronizing positions of the motor and of the generator considered as separate machines. The synchronizing positions for the separate machines are equal in number to the number of pairs of poles. Thus in the 4-pole-10-pole set shown in Fig. 27 there are two synchronizing positions for the motor, considered alone; there are five synchronizing positions for

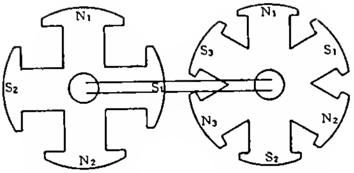

FIG. 26—40 TO 60 CYCLES; 4 AND 6 POLES

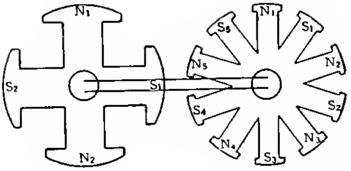

FIG. 27—25 TO 62.5 CYCLES; 4 AND 10 POLES

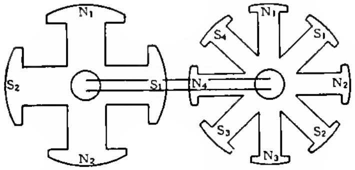

FIG. 28—25 TO 50 CYCLES; 4 AND 8 POLES

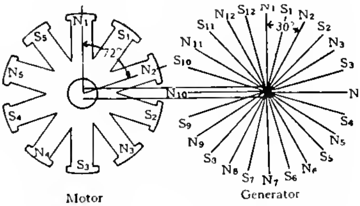

FIG. 29—25 TO 60 CYCLES; 10 AND 24 POLES

the generator, considered alone; and there is only one synchronizing position for the set; in the 4-pole-8-pole set, in Fig. 28 there are two synchronizing positions for the set; or as many as for the motor, considered alone; in the 10-pole-24-pole sets in Fig. 29, there is, again, only one synchronizing position for the second set.

If the number of correct synchronizing positions of the motors or generators, considered separately, is increased, the number of synchronizing positions for the second set will also be increased. Thus, if the polarity of the south poles of the incoming generator, considering the two generators as separate engine-driven units, be changed, each of the generator poles, at one time or another, will be a north pole, and there will be as many synchronizing positions as there are poles. Considering the motors alone, by reversing the motor excitation, the number of motor synchronizing positions may also be doubled. In the 5-pole-6-pole set (Fig. 26) it was shown that if pole N_1 of one motor had the same position as pole N_2 of the second motor, the pole N_1 of the first generator would have the same position as pole S_2 in the second generator, and that the two generators would be 180 degrees out of phase. Obviously, by reversing the excitation of the second generator, the south pole is changed to a north pole., thereby bringing two generator poles of the same polarity into the same position, and the two sets into synchronism.

In the 10-pole-24-pole combination (Fig. 29) the number of set synchronizing positions can be increased by reversing the motor excitation. Consider that the two motors are connected to the supply circuit so that the poles N_1 of both motors are in the same position. Generator poles of the same polarity will also be in the same position, but the generators are not connected in parallel.

Now assume that the excitation of one motor is reversed. The pole N_1 (which is now a south pole) will drop back and the pole S_1 will occupy the position that N_1 did occupy. The motor has droped back one pole—or as it is called has "slipped a pole"—and its new position is 180 magnetic degrees or 36 mechanical degrees behind its original position. The generator of the second set has been pulled back 36 mechanical degrees or 432 magnetic degrees. Pole N_2 of the second generator is now 6 mechanical degrees or 72 magnetic degrees back of pole N_1 of the first generator. If this process of slipping a pole is repeated until pole S_2 of the second motor is in the same position as pole N_1 of the first motor pole, N_7 of the second generator will be in the same position as pole N_1 of the first generator, and the two sets will be in synchronism on both ends. In practical operation, the second motor may be connected to the circuit in any one of five polar positions (considering only one direction of excitation); if the generator poles have different positions, they may be brought into the same position by slipping a motor pole as often as may be necessary.

It will be noted from the preceding discussion that the number of synchronizing positions depends on the number of poles in the motor and generator of the set; that with some pole combinations number of correct positions is increased by reversing the generator excitation, and, in others, by reversing the motor excitation. These results may be summarized as follows:

(1) The number of synchronizing **positions of the incoming** set with a single direction of excitation, in **both motor and generator,** is the greatest common divisor of the number of **pairs of poles** in motor and generator of the incoming set;

(2) The number of synchronizing **positions of the incoming** set, with both directions of excitation in **both motor and generator,** is the greatest common divisor of the number of **poles** in motor and generator of the incoming set.

(3) The number of synchronizing positions of the incoming set with both directions of excitation in **either** motor or generator, is the greatest common divisor of the number of pairs of poles of the machine with a single direction of excitation and the number of poles of the machine with both directions of excitation.

Whether the installation of a field reversing switch for the motor or generator or for both is of any value, may be determined from the rule just given. Thus in the 10-pole-24-pole set with both directions of excitation for the motor, the number of synchronizing positions is 2 (the greatest common divisor of 10 and 12) ; with both directions of excitation for the generator, the number of synchronizing positions is 1 (the greatest common divisor of 5 and 24) ; with both directions of excitation for both generator and motor the number of synchronizing positions is 2 (the greatest common divisor of 10 and 24). Therefore, a field reversing switch for the motor is desirable, but a similar switch for the generator is of no benefit.

This information for the pole combinations ordinarily used is given in the following Table I. This information applies whether the set is started from the low frequency or from the high frequency end.

Table I—Polar Connections of Frequency Changers

Motor Poles	Gen. Poles	Direction of Excitation Motor	Gen.	Syn. Positions Motor Alone	Gen. Alone	Set	Motor (Low Freq.) Field Sw. Req.	Gen. (High Freq.) Field Sw. Req.
4	10	Single	Single	2	5	1	..	..
..	..	Both	Single	4	5	1	No	
..	..	Single	Both	2	10	2	..	Yes
8	20	Single	Single	4	10	2	.	..
..	..	Both	Single	8	10	2	No	.
..	..	Single	Both	4	20	4	..	Yes
10	24	Single	Single	5	12	1	..	..
..	..	Both	Single	10	12	2	Yes	..
..	..	Single	Both	5	24	1	..	No

Mechanical Adjustment of Two Frequency Changers—Before two frequency changers can be safely connected in parallel on both motor and generator ends, the relative location of the field poles and armature winding of one set must be made identical with the relative location of the same parts of the second set, so that when the two motors are properly synchronized as just described, the two generators will be in phase. Even in sets of duplicate design, ordinary manufacturing variations usually prevent two sets from being operated together in this way without some adjustment. Obviously, with sets of different sizes and with sets made by different manufacturers, the need for adjustment will be greater. This requirement is met by supporting one frame—usually the motor frame—in a cradle in which the frame can be rotated through a small angle. Shown in Fig. 25.

Frame Adjustment at No Load—The two sets to be adjusted should be synchronized on the motor ends until the least possible difference exists in the generator phase. If the generator switchboard contains a synchroscope, this adjustment will be greatly facilitated. If any difficulty is experienced in determining the best motor synchronizing position, a systematic study, as outlined below, should be made.

(1) Mark a radial line on some accessible part of a motor pole and place a mark on a generator pole that is in line with it, the two marks lying in the same radial plane. It will be found convenient to use the motor pole and the generator pole that are approximately in line, if such exist. Place the rotor of both sets in such positions that the lines on the motor poles are in line with the armature slots containing the terminal coil of the A-phase. Observe the angular difference, if any, between the mark on the generator pole and the slot containing the terminal coil of the A phase of the generator in both sets. If this angular difference is the same in the two sets, no frame adjustment will be required. If it is not the same, the frames of one or both sets will have to be moved to make it the same. An approximate adjustment of the frame can be made from these mechanical measurements, but the final accurate adjustment must be made by operating the two sets. If these mechanical measurements indicate that the two sets are widely different (more than 3 or 4 degrees difference in generator rotor position with respect to the terminal coil) the difference can be reduced by electrical adjustments described later.

(2) With one set running with full voltage on the motor and with the generator on open circuit, start the second set, synchronizing the motor with the supply system. Note the synchroscope reading. Cause the second motor to slip a pole by reversing the field excitation (see pages 59-60) and again note the synchroscope reading. (The motor will more readily slip a pole if it is operated on the starting voltage, assuming that the motor is alternating current self-started, but care should be taken that it is not operated from the starting taps for a long enough time to overheat the starting auto-transformers). Note the reading of the synchroscope for each rotor position of the second motor. It is not necessary to experimentally observe the synchroscope readings with reversed generator excitation, as these will be 180 degrees displaced from the corresponding reading with the original direction of excitation. These should be set down together with the observed readings and these readings should be compared with the theoretical difference in generator rotor position. Such a set of readings for a 4-pole-10-pole set is given in Table II for purposes of illustration.

Table II—Comparison of Synchroscope Position for Different Rotor Positions

Rotor Position of Second Motor	Actual Difference in Gen. Phase by Synchroscope	
	Orig. Excitation	Rev. Excitation
1	100° Fast	80° Slow
2	10° Fast	170° Slow
3	80° Slow	100° Fast
4	170° Slow	10° Fast

The theoretical difference in generator rotor position, assuming correct mechanical adjustment, is shown in the following Table III:

Table III—Difference in Generator Rotor Position of a 4-Pole-10-Pole Set

Rotor Position of Second Motor (Rotor Position of First Motor=N_1)	Rotor Position of Second Generator as Compared with N_1 of First Gen.	
	Orig. Excitation	Rev. Excitation
N_1	0°	180°
S_1	90° Behind	90° Ahead
N_2	180°	0°
S_2	90° Ahead	90° Ahead

Comparing the figures in Tables II and III, it is evident that the second generator is set 10 electrical degrees ahead (i. e. "FAST" as indicated by the synchroscope) of its correct position, with the motor in No. 2 position. The two generators will be brought into the same polar position if the second motor is synchronized in No. 2 position and the frame of the second motor is moved 10 electrical degrees (2 mechanical degrees) in the direction of rotation.*

The theoretical difference in generator rotor position, assuming correct mechanical adjustment for 10-pole-24-pole set, are shown in the following table:

Table IV—Theoretical Differences in Generator Rotor Positions

Rotor Position of Second Motor (Rotor Position of First Motor=N_1)	Rotor Position of Second Generator as Compared with N_1 of First Gen.	
	Orig. Excitation	Rev. Excitation
N_1	0°	180°
S_1	72° Behind	108° Ahead
N_2	144° Behind	36° Ahead
S_2	144° Ahead	36° Behind
N_3	72° Adead	108° Behind
S_3	0°	180°
N_4	72° Behind	108° Ahead
S_4	144° Behind	36° Ahead
N_5	144° Ahead	36° Behind
S_5	72° Ahead	108° Behind

---

*The movement of a pole in the direction of rotation advances the phase of the generated voltage and a movement of an armature coil (or frame) in the direction of rotation retards the phase. This is true whether the motor or generator frame is moved to adjust the generator phase.

(3) It is possible, if the two sets are of dissimilar manufacture, for the second generator to be out of phase, when tested as just described, by a larger angle than can be corrected by the maximum frame movement permitted by the cradle. The out-of-phase angle (A to C, C to B, and B to A) may be reduced in most sets by advancing all motor armature leads so as to change the motor phase 120 electrical degrees (in a three-phase motor) or 90 electrical degrees (in a two-phase motor). A change of 1 electrical degree in the motor phase results in a change of 2.5 degrees in the generator phase in the 4-pole-10-pole set or a change of 2.4 degrees in the 10-pole-24-pole set. The generator phase can similarly be changed by changing the generator winding 120 degrees or 90 degrees (depending on the number of phases). These changes do no good in the case of a 4-pole motor having a two-phase armature winding, or, for example, in the case of a 6-pole motor having a three-phase winding.

If all the possible electrical adjustments are made—that is—if the motor is synchronized in all possible positions, if the generator field is reversed and if the motor and generator leads are interchanged as described—the frequency changers can be synchronized within a very small angle (in mechanical degrees). If, after attempting to adjust two sets and the smallest obtainable generator phase difference is greater than can be corrected by the frame movement provided further electrical adjustments should be made, making use of the mechanical measurements described on pages 61-62 as a first approximation to the change in phase angle that is required.

The electrical adjustments that can be made are indicated by the following example showing the maximum frame movement that would be required in a set having a **four-pole-three-phase motor, and a ten-pole three-phase generator:** Assume that one set differs from the other in generator phase to the greatest possible extent. Obviously, it can differ by no more than 180 electrical degrees. However, any difference greater than 90 degrees can be changed to a differenc less than 90 degrees by reversing the generator field excitation. If in any synchronizing position of the second motor the generator phase difference is 90 degrees, this can be reduced to zero by making the motor slip a pole. Therefore, any phase difference greater than 45 degrees can be changed to a difference of less than 45 degrees by reversing the motor field excitation. If the motor armature leads are advanced one terminal, the motor phase will be changed 120 degrees or 300 degrees in generator phase $(120 \times \frac{10}{4})$. If this change be added to the previously existing difference of 45 degrees, there will be a difference of 345 degrees which is equivalent to a difference (in the opposite direction) of 15 degrees (360 — 345). In this set, a change in generator terminals produces the same change in generator phase as does a change in motor terminals. If the motor armature is two-phase, no new combinations can be obtained that could not be obtained by slipping a motor pole, for both changes result in a change of 90 degrees in motor phase.

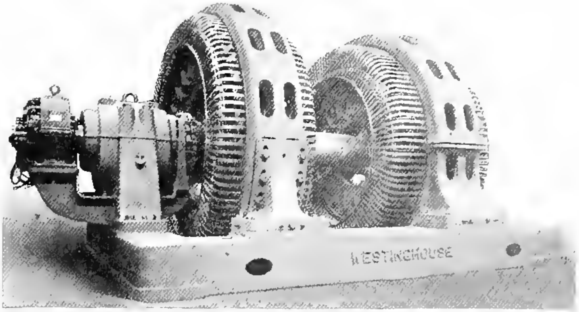

FIG. 30—6835 KVA., FREQUENCY CHANGER WITH DIRECT-CONNECTED EXCITER

If no generator synchroscope is available, lamps may be used. Since lamps give no definite indications of the angle of generator phase difference, greater dependence must be placed on the mechanical measurement of generator phase difference described on pages 61-62. When the generators are nearly in phase, they may be connected in parallel and a more accurate adjustment made. The field currents should be adjusted for equal voltages before the generators are connected together and the field currents should not be changed thereafter. A current will flow in the generator armatures that will be proportional (for small angles) to the phase difference. The frame should be moved slightly and the effect on the current noted. The frame should then be moved in the proper direction until no current flows in the generator circuit. If the field excitation is not correctly adjusted as described above before the generators are paralleled, the armature current cannot be reduced to zero by moving the frame. The current that circulates in the two generator armatures due to phase differences is an energy current—one greater will be acting as a generator supplying power to the other generator, driving it as a motor. The two motors of the frequency changers will, therefore, indicate whether the current flowing in the generators are due to mechanical phase differences or to differences in field excitation. In the former case, the currents taken by the motors will be much greater than required by the losses of the set, and one motor will be acting as a generator (a wattmeter will show reversed power).

Division of Load Between Two Sets Operating in Parallel— If two sets are correctly adjusted, mechanically, as has been described and if they are properly synchronized, they will operate in parallel on both motor and generator ends without cross-currents, assuming that the field excitation is properly adjusted and that there is no load on the generator bus. As the load is connected, the load division between the two sets may be proportional to their ratings, or it may not, depending on the comparative design proportions of the two sets.

As a synchronous motor is loaded, the phase of the counter electromotive force of the motor changes, the phase of the motor electromotive force dropping behind the line electromotive force as the load increases. The phase of the line electromotive force may be visualized as the position of a motor pole (in a two-pole rotating field motor) if the motor carries no load whatsoever; and the phase of the motor electromotive force may be represented by the position of the **opposite** pole at the various loads applied to the motor, at the time that the same instantaneous value and direction of line electromotive force exists. As load is applied to the motor, the position of the opposite motor pole will drop behind the position it had with no load at the chosen reference time; and the amount of the difference will be found to increase as the load increases.

This change in rotor position is due to two actions; viz., the shifting in resultant flux due to the increase and the change in phase of the armature reaction, and the lag in counter e.m.f. due to the internal voltage drop in the motor.

The same change in rotor position occurs in the generator end of the set, and for the same reasons. These changes in position in motor and generator are such that they are cumulative.

Two sets having synchronous motors will divide the available load in such a way that the angle of total phase shift, due to the load, will be the same in the two sets. If one set is designed, so that it drops back a smaller angle when carrying its rated load than does the other sets, then the first sets will carry more than its proper share of the load.

If two sets do not satisfactorily share the load, there is no possible adjustment that will improve the load division at all loads. The load division at some particular load such as rated load may be improved by advancing the phase position of the motor or generator carrying less than its proper share of the load, this being done by moving the frame in the cradle. This will increase the load taken by the set by the same amount at all loads, so that at light loads this set will take more than its share and at no load will motorize the generator of the other set.

Any factor that changes the angle of phase shift in either motor or generator will change the load division. Thus, if two duplicate sets are operating in parallel and carrying equal loads, the load can be partially shifted from one to the other by changing the excitation of either motor or either generator. A change in the low frequency machine is more effective than in the high frequency machine, on account of the larger mechanical angle for a given electrical angle in the lower frequency unit.

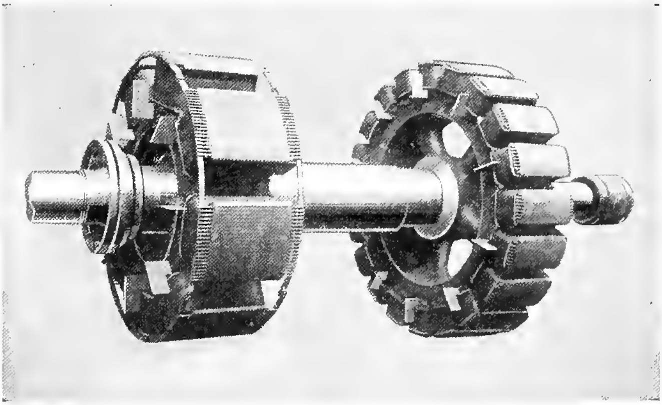

Fig. 31—Rotor of a Typical Frequency Changer

If the frequency changer has induction motors instead of synchronous motors, the load division is determined by the relative "slips" of the two motors. In this case, an actual drop in speed occurs as in the direct-current motor or engine-driven generator.

Synchronizing an Unloaded Set With a Loaded Set—The fact that both the motor counter electromotive force, as compared with the line voltage, and the generator terminal electromotive force, as compared with the generator internal electromotive force, shift in phase, in the same direction as the load increases, introduces a new factor in synchronizing a loaded and unloaded set. If the two sets are correctly adjusted for exact synchronism at no load, it will be impossible to exactly synchronize an unloaded set with another set that is transferring power between two systems. It will usually be satisfactory to connect the two generators together, even though exact synchronism does not exact.

In connection with this question of synchronizing an unloaded set with a loaded set, it is interesting to point out that the total shift in phase, due to load, is greater when power is transferred from the low frequency system to the high frequency system than when the direction of power flow is reversed. The reason for this is, of course, the fact that the phase shift of the motor, expressed in generator electrical degrees, is the motor electrical angle multiplied by the ratio of the generator poles to the motor poles. This ratio is obviously greater than unity when the motor is the low frequency machine, and less than unity when the motor is the high frequency machine. In extreme cases of phase shift due to load, this fact might be made of practical use if it happens that when a second set is to be synchronized, the direction of power flow can be made such as to secure this smaller angle of phase shift.

OPERATING INSTRUCTIONS
FREQUENCY CHANGERS

General Instructions—Before starting a frequency changer the following routine should be regularly observed.

(1) The collector ring brushes should be examined to see that they move freely in their holders.

(2) See that no loose material, such as a bolt or a tool, is near enough to the moving or live parts of the set to cause damage.

(3) See that all switches in both motor and generator circuits are open.

(4) Examine the bearing housings to see that there is oil in the wells and that the oil rings turn freely.

(5) When the set has been started examine the oil rings to see that they are revolving properly and examine the collector ring brushes to see that they are not sparking.

Starting a Single Frequency Changer—The operations in starting the motor will be identical with those in starting the motor of motor generators given on pages 46-50. The same methods of starting may be used.

Starting with Oil Pressure System—When such a system is installed the following additional instructions should be followed:

(1) Before voltage is applied to the motor armature or starting motor (as the case may be) start the motor-driven oil pump. The oil pressure will first increase to 800 to 1200 pounds per square inch (depending on the pressure between the shaft and bearings and the ratio between the area subjected to oil pressure and the total bearing area) and as soon as the rotor is lifted the oil pressure will fall to about one-half of the initial value.

(2) As soon as the rotor has been raised as shown by the

oil pressure or by the sound that accompanies the lifting of the rotor, close the starting switch.

(3) The oil pump should be shut down as soon after the set begins to revolve as may be convenient.

To Connect a Single Generator to Its Line—

(1) If there is no other alternating-current power source connected to the same load close the generator oil switch and adjust the generator (or exciter) rheostat to give the desired voltage.

(2) If there is another source of alternating-current power with which the generator of the frequency changer must operate in parallel the two systems must synchronize through the frequency changer. This can only be done by changing the speed and frequency of the generators of either primary source of power. Usually the frequency changer is located in the same station with the generators of one frequency and obviously it will be most convenient to synchronize by adjusting the speed of these generators.

This condition applies to induction-motor-driven sets as well as to synchronous-motor-driven sets. While the speed of a set driven by an induction motor, having a phase-wound secondary, is under control when carrying load (by changing the resistance in the secondary circuit) the speed can not be appreciably changed at no load for synchronizing purposes on account of the negligible secondary voltage and current.

Starting a Second Synchronous-Motor-Driven Frequency Changer—It will be assumed that one set is in operation and carrying load.

(1) Start the motor of the second set and synchronize it, if motor started, with the supply system. If it is self started leave the switch in the starting position.

(2) Synchronize the incoming generator with the loaded generator. This can not be done exactly on account of the phase shift of the loaded set (see page 65). This phase difference between a generator carrying full load and one unloaded, for any particular installation should be determined from the synchroscope reading when it is known that the generators are correctly synchronized. For methods of synchronizing see pages 57 to 61.

(3) When the unloaded generator is as nearly in phase as it is possible to make it close the generator oil switch. The incoming generator will automatically take its share of the load.

(4) Adjust the field current of the second generator to secure the same power factor on the two generators.

Starting a Second Induction-Motor-Driven Set—

(1) The motor should be started as previously described (pages 46-50). The speed of the unloaded set will be higher than that of the loaded set.

(2) Open the motor line switch and, as the set drifts, the speed will approach the speed of the loaded set.

(3) Close the generator switch when the two generators are in synchronism.

(4) Close the motor line switch. The motor will automatically take on a load corresponding to the "slip" forced by the operation of the two generators in parallel.

(5) Adjust the generator field current of the incoming generator to secure the same power factor on both generators.

Disconnecting a Loaded Frequency Changer—If the sets are synchronous-motor-driven the load on the set can not be gradually dropped. It is necessary to open the generator oil switch, immediately transferring the total load to the remaining units.

If the set to be disconnected is induction-motor-driven and the induction motor is phase wound, it is possible to transfer the load from one generator to the other by increasing the secondary resistance of the set about to be shut down and decreasing the secondary resistances of the remaining sets. The generator switch can then be opened without shock to the remaining sets.

CARE AND MAINTENANCE OF MACHINES

Caution—At all times keep the motors and generators clean and free from oil and dust, especially from copper or carbon dust. With high-voltage machines a small accumulation of dust on the windings may be the cause of serious **burn-out.** In stations of sufficient size to warrant the expense it is advisable to install an air pump for supplying compressed air with a piping system so distributed that a short section of hose will enable the attendant to reach all parts of the winding on any machine to blow out the dust. The pressure used in such service should not exceed 25 pounds per square inch, as a high pressure may lift the insulation wrappings and blow dust inside the coils. Always allow any accumulation of water in the pipes to be blown out before turning the air blast on the machine.

In blowing out machines, adjacent machines should be protected from flying dust by a suitable cover or shield.

A preferable method of cleaning machines is by a vacuum cleaning system whereby all the dirt is carried away from the machines and the danger of blowing dirt into adjacent machines is completely avoided.

Where insulated parts, subject to copper or carbon dust, are accessible they should be wiped clean with a dry cloth, in addition to cleaning as described above.

It will facilitate the cleaning of insulated parts if they are painted with insulating varnish at regular intervals. At the time selected for painting the machine should be given a suitable high-voltage insulation test to locate possible weaknesses at a time when they can be conveniently repaired.

Bearings—When first starting a machine particular attention must be given the bearings to see that they are well supplied with lubricant. The oil rings should revolve freely and carry oil to the tops of the journals. It is well to allow a new machine to run for an hour or two with no load, watching the bearings closely for any indications of undue heating. The bearings of all Westinghouse machines are liberal in size, and with proper care will not give trouble. They may, however, be made to overheat by any of the following causes:

(1) Insufficient lubrication which may be due to:
  (a) Poor lubricant.
  (b) Insufficient quantity.
  (c) Failure of oil rings to revolve.

(2) Poor aligning or leveling causing excessive end thrust or binding.

(3) Rough bearing surface which may be caused by careless handling, or the presence of dirt or gritty substances in the oil or grease.

(4) Bent shaft.

A bearing is usually safe if it operates at a constant temperature below the boiling point of water, 212 degrees Fahrenheit (100 degrees Centigrade). The rapid rise of temperature toward this limit, however, is a danger signal calling for prompt attention. A bearing will be safe below this temperature, even when hot enough to burn the hand held continuously against the outside a few seconds. It will seldom be necessary to do more than to supply a hot bearing with an abundance of fresh clean lubricant, making certain that the oil reaches the bearing surface. If this is not effective, pour a heavy lubricant directly onto the journal. Keep the rotating part in motion enough to prevent the bearing from becoming set or "frozen."

In normal service the old oil should be withdrawn from bearings occasionally and fresh oil substituted, running enough of the fresh oil through the bearings to wash out all sediment. The old oil as well as that used for rinsing can run through a filter and used again. A good oil filter is a necessity in every plant where much machinery is in use. The frequency with which the bearings must be refilled depends so much on local conditions, such as the severity and continuity of the service, the room temperature, the state of cleanliness, etc., that no definite instructions can be given. Until local conditions show another interval to be more suitable bearing should be refilled every six months.

Oil—Only the very best grade of dynamo oil should be used. In the long run it always proves a false economy to use cheap oil. If the oil is to be used a second time it should be filtered and if warm allowed to cool before the bearings are refilled. Even new oil should be examined carefully and filtered or rejected if it is found to be gritty.

Commutator Seasoning and Grinding—The satisfactory operation of a direct-current generator is more dependent on the condition of the commutator than on any other one item. It is also an equally well recognized fact that a commutator only becomes thoroughly "seasoned" (the insulation baked out and all parts in their final set position) after operating for a considerable time followed by the necessary tightening and grinding. Owing to lack of time and of sufficient facilities for current loading at the Works, it is not feasible, in all cases, to get the commutators finally seasoned before shipment. It should be expected that a certain amount of tightening and grinding must be done after the generator is put into service, particularly if the commutator is of large size. This work should only be done under supervision of an experienced man and after obtaining detailed information from the Works regarding the commutator construction.

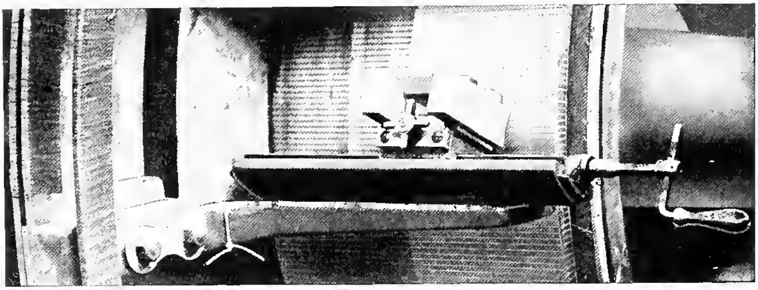

FIG. 32—GRINDING DEVICE FOR TRUING COMMUTATORS

That the commutator needs attention will usually be indicated by its becoming rough due to a general unevenness, high or low bars, flat sections or eccentricity. If these conditions are not corrected they will result in poor commutation, overheating of the commutator, a rapid deterioration of the brushes, clips and pigtails, and greatly limit the machines ability to satisfactorily handle overloads.

If the commutator is in very bad condition it may be necessary to use a turning tool, but for ordinary cases a grinding tool, Fig. 32 is preferable and is recommended. Commutators should always be ground at from 100 to 120 per cent normal speed. Turning requires a much lower speed; it should not be higher than 150 feet per minute. Before grinding a commutator, the machine should have been in service a sufficient length of time to bring the temperatures up to a constant value; it should then be shut down and the bolts holding the commutator "V" ring shown in Fig. 33 should be tightened. The commutator should then be ground or turned down to a true surface

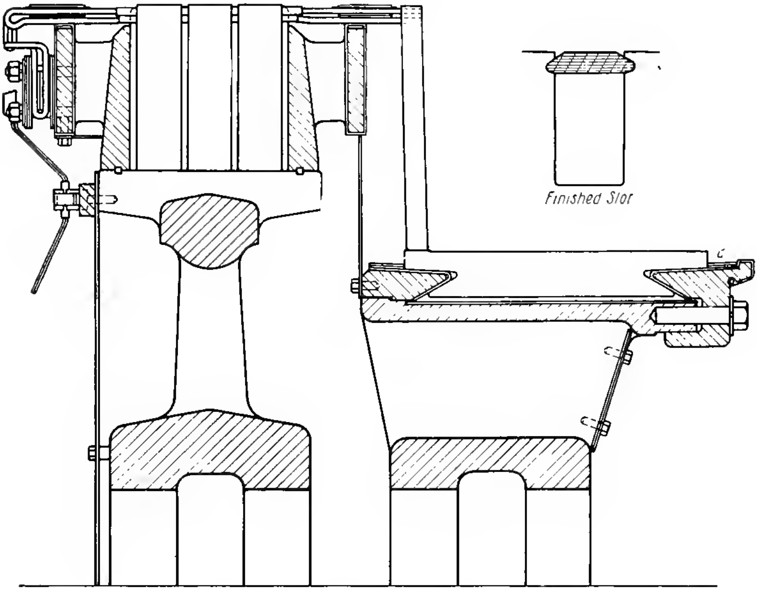

Fig. 33—Section of Commutator Showing V-Rings

Before grinding, the brushes should be lifted off the commutator as the copper and stone dust will rapidly wear them off. The dust will also become imbedded in the brush contact surface and later damage the commutator or cause poor commutation. The armature winding should also be thoroughly protected during this operation to prevent an accumulation of dirt and metal chips which may result in an insulation failure when the machine is again put in service. This protection can usually be obtained by using a circular shield of fullerboard, or similar material, around the commutator at the end next to the armature. (See Fig. 32). This shield can be easily supported from the brushholder arms and should extend from the commutator surface to an inch or two above the surface of the armature. It may also be desirable to put a temporary canvas hood over the armature winding. This protection can be best provided by carrying the copper dust away by means of a vacuum system. Even when this is done the armature should be protected as described. After grinding, the complete machine should be thoroughly cleaned by the methods already described. It may be necessary to repeat the heating, tightening and grinding one or more times before the commutator is in first-class condition. Emery cloth or paper should never be used for this purpose on accaunt of the continued abrasive action of the emery which becomes embedded in the copper bars and brushes. Even when sandpaper is used the brushes should be raised and the commutator wiped clean with a piece of canvas lubricated with a very small quantity of vaseline or oil. Cotton waste should never be used and an excess of lubricant must be avoided.

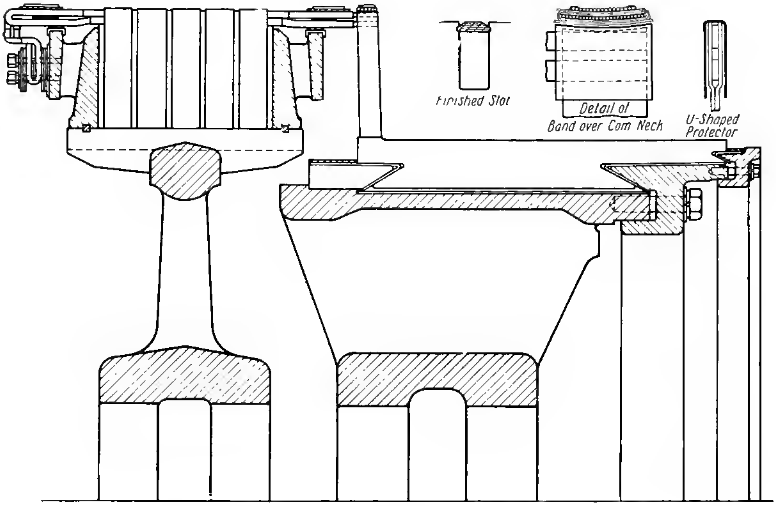

FIG. 34—SECTION OF COMMUTATOR SHOWING AUXILIARY V-RINGS

In tightening commutators having auxiliary V-rings (Fig. 34) the auxiliary V-ring or the V-ring at the outside end of the commutator should first be slightly loosened, then the main and auxiliary "V's" tightened in the order named.

In cases where the operating temperature of the commutator is not sufficiently high to bake out the insulation it may be heated up by running the generator on short-circuit, driving it from some external source. It may also be heated by external sources, but due to the inability to heat uniformly in this way, the former method is to be preferred.

In heating up the commutator by running on short-circuit the armature terminals should be connected together and the field so excited that as much current as possible will flow through the windings without overheating or injurious sparking at the commutator. The excitation necessary will be very small, and high resistance, such as lamps, should be used in series with the field.

In commutating-pole machines the series-commutating winding should be left in series with the armature on short-circuit. This will permit much higher current to circulate before the point of injurious sparking is reached. Care should be taken that the brushes are on the "neutral" position before running under this condition; otherwise the machine will build up as a series generator and current sufficient to damage it may be generated. To avoid this a circuit-breaker should be wired in circuit in series with the armature and commutating poles. With this connection the separate excitation of the shunt field will probably not be required, the current being controlled by shifting the brushes away from "neutral."

During such a run the tension on the brushes should be adjusted to as high a value as possible so that their friction will increase the heating effect. A spare set of carbons should be used for this run as the rough commutator and excessive sparking that usually takes place will likely render the regular set unfit for future use. It will also hasten results, if the machine is driven at 20 per cent overspeed during the heating run. If the bars show a tendency to rise, shut down and tighten the V-rings while the machine is still hot.

Undercutting Commutator Mica—All standard commutators have the mica between bars undercut 1-16 inch. **After grinding or turning, the slot due to the undercutting should be cleaned out and the edges of the bars scraped to remove burrs and then well rounded off.** It is particularly important that the edges of the bars be well rounded. Failure to do this has caused machines to buck on sudden changes in load or when the circuit-breaker opens.

If it is necessary to reundercut the mica due to grinding or turning the commutator or due to wear after long operation this may be done with a hack saw blade held between suitable guides, or, more conveniently and accurately with motor-driven circular saws. Electric and air-driven tools for this purpose are made by the Westinghouse Electric & Manufacturing Company (See Fig. 35).

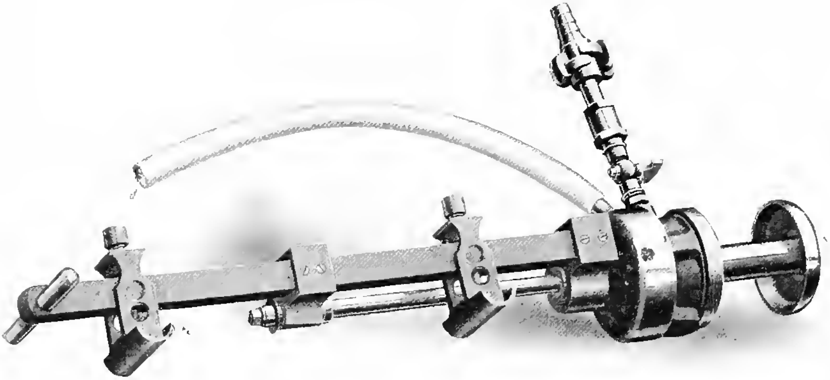

FIG. 35—SMALL PORTABLE TOOL FOR UNDERCUTTING MICA.—ATTACHED TO AIR MOTOR

Care of Commutators—After a commutator is well seasoned it should be kept clean by occasional wiping with a canvas cloth moistened with a slight amount of clean lubricating oil. An excessive use of oil, grease, vaseline or so-called commutator compounds will gum up the commutator causing a deposit of carbon and metal dust on the surface and particularly in the undercutting that may cause "burning" and "flashing."

Some commutators run dry even when graphite brushes are used and a slight amount of lubrication is necessary. In all cases, however, commutators with graphite brushes should operate satisfactorily without frequent lubrication; two hours represent a reasonable minimum interval. When lubrication is required at shorter intervals a change in the grade of brushes or in brush rigging adjustment should be considered.

The ideal appearance of a commutator surface is a polished dark brown or chocolate color. Such a commutator needs no attention other than cleaning.

Sparking at Direct-Current Brushes—Sparking may be due to either mechanical causes or electrical causes. If the former causes is responsible, sparks are usually small "pin sparks" due to breaking of contact between the brush and commutator or small "streamers" due to particles of carbon breaking off the brushes. In either case the amount of sparking varies little, if any, between "no load" and "full load." The more usual mechanical causes of sparking are:

(1) Rough commutator, due to high bars, high mica (if commutator is not undercut), flat spots, or rough edges of undercutting.

(2) Vibration, originating in brush rig.

(3) Wrong or unequal brush tension.

(4) Brushes stuck in holders.

If the sparking is due to electrical causes, the sparking varies greatly as the load is increased and the sparks are larger and have more "snap" or "bite" than when the sparking is caused by mechanical defects. The brush contact surface is usually a true indication of the cause of sparking. If the surface is eaten away or "honey-combed," the sparking is almost sure to be due to electrical causes. The more common electrical causes of sparking met with in operation are:

(1) Brushes on all arms or on part of the arms incorrectly set with respect to neutral points (See page 25).

(2) Brushes of wrong composition or resistance.

(3) Incorrect adjustment of commutating-pole winding (see page 27).

(4) Operation of non-commutating-pole generators at voltages lower than that for which the generator was designed.

(5) Hunting—In this case sparking will be periodic, corresponding to the frequency of oscillation of armature.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator, and may be recognized by the scarring of the commutator at the point of the open circuit. If a lead from the armature winding to the commutator becomes loose or broken it will draw a bright spark as the break passes the brush position. This trouble can be readily located as the insulation on each side of the disconnected bar will be more or less pitted.

If sparking occurs that cannot be accounted for by overloads or other service conditions, wrong adjustments, or mechanical defects, an experienced engineer should be consulted to determine the cause and remedy.

"Bucking" or "flashing" between arms of opposite polarity is usually caused by excessive voltage generated in the coils short-circuited by the brush or between adjacent commutator bars, or abnormally low surface resistance on the commutator between adjacent brush arms. Any conditions tending to produce poor commutation increases the likelihood of "bucking." Bucking is usually caused by the following:

(1) Rough or dirty commutator.

(2) A drop of water on the commutator, from the roof, leaky steam pipes or other source.

(3) Excessive overloads or short-circuits on the direct-current line.

"Bucking" or "Flashing" Remedies—If flashing continues after the first two possible causes have been eliminated the trouble will usually be due to causes external to the machine.

Flashing can in most cases, especially on railway generators be traced to excessive overloads usually caused by short circuits. The most effective way is to increase the resistance in the feeder circuits which can be done as described on page 24. A readjustment of machine and feeder breakers will very often improve results. Experience has shown that the majority of flashing troubles on generators are due to external local conditions which must be corrected to obtain the best results.

Speed Limit Device—At frequent intervals the overspeed switch, wiring and circuit-breaker tripping coil should be tried by operating the trip lever by hand. Occasionally, the readjustment and condition of the centrifugal tripping device should be checked by actually operating the machine at the overspeed at which the tripping device is set to operate.

REPAIRS

Ordering of Repair Parts—Repair parts of any standard Westinghouse set may be secured on short notice. To avoid misunderstanding always give the serial number of the stationary or of the rotating part of the machine, as the case may be. The former will be found stamped on the nameplate and the latter on the end of the shaft. When material for coils is ordered, it should also be stated whether or not insulation for the winding is also desired.

Rebabbitting Bearings—The old babbitt should first be melted out and a suitable mandrel prepared. Split bearings should be babbitted one-half at a time and the mandrel should consist of a half-cylinder with shoulders running along its length on which the sides of the bearings may rest so as to form a close fit when the bearing housing is in position for babbitting. Pieces of felt should be placed between the ends to prevent the babbitt from running into the oil well in the spaces back of the bearing shell. Use only the best babbitt metal. The melted babbitt should be poured in the gate until it begins to overflow, and a few moments should elapse before it is removed from the mandrel, in order that the bearing may become quite hard. The bearing housing should then be fored or reamed to the proper size, the holes for inspecting the working of the oil rings drilled, and the oil ring slots melted or cut to the proper

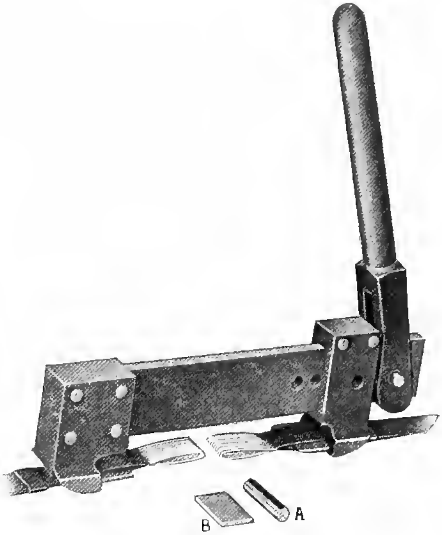

FIG. 36—BANDING TOOL

depth. The finishing can be done with a file. If the mandrel is a smooth half-cylinder the oil grooves should be chipped out. The grooves may be cast by properly designing the mandrel.

Repairs to Insulation—If a defect develops in the outside of a field or armature coil, it can sometimes be repaired by carefully raising the injured wire or wires and applying fresh insulation. More extensive repairs should not be attempted by inexperienced, or unskilled workmen.

Sectional Bands—Large generator armatures are provided with sectional bands instead of the more familiar continuous bands, greatly facilitating the repair of large armatures.

Fig. 36 shows the tool used in connecting and disconnecting sectional bands.

To make the final connection between the free ends, after the different sections have been keyed together into an open hoop and are in position on the armature, place the tool as shown in Fig. 36, the two jaws gripping the projecting ends of the fixed pieces let into the ends of each section for this purpose. With the tool in the position shown in Fig. 36, bring down the handle, forcing the movable jaw forward along the beam and interweaving the loops on the section ends. Insert the steel pin A in the holes through the movable jaw and beam, and with the tool clamped in this way, remove the handle and advance it to the next hole in the beam. This operation is repeated until the ends of the band are interlocked sufficiently to permit the steel key piece B to be inserted (see Fig. 36). All that remains is to remove the tool and paint or shellac the joint.

To remove the band, reverse the preceding process. Relieve the tension on the joint by tightening the band with the tool and then drive out the key piece.

CAUTION

In soldering connections use an acid that will not act on the insulation or the copper; an alcoholic solution of resin is a suitable soldering flux.

In soldering commutator connections do not allow bits of solder to drop down where they may short-circuit ocmmutator bars.

Keep the commutator, brushes and insulation clean.

Never use emery cloth or emery paper on commutator, collector or brushes.

DIAGRAM OF CONNECTIONS

The diagrams of connections on the following pages are typical only. If, as in Fig. 37, the motor is shown as being excited from the generator which it drives, it does not follow that the motors for all 250-volt direct-current sets are excited in this manner. A different type of alternating-current starter has purposely been shown on each diagram so as to illustrate various combinations used in practice.

In an actual installation two single-phase auto-transformers may be employed for a certain motor voltage where the diagram shows a three-phase transformer and vice versa.

Protection against power reversal has been indicated for all synchronous-motor direct-current generator sets, although it is required only when the set operates in parallel with an independent source of direct-current power.

The low voltage trip on the motor circuit-breaker may not be included where the set is installed in the generating station and under the control of one operator who also controls the power supply to the set.

Hand operated motor circuit-breaker starters have been shown but these may be furnished electrically operated when the sets are located in large stations where direct-current control circuits are available or where the station capacity is so large that positive and speedy closing of the starters must be insured. In such cases a standard starter, if used, would have in series with it an instantaneous trip heavy duty circuit-breaker, set high to trip on short-circuits only. The starter would then be non-automatic or, if overload automatic, would be equipped with relays having a definite minimum time delay in operation so that only the heavy duty breaker will open in case of a short-circuit. If low voltage trip is necessary, it is placed on the heavy duty breaker as otherwise the starter might open first in case the system voltage drops abnormally under short-circuit conditions.

The meter equipment shown for the synchronous motors is the simplest necessary for indicating proper operation. Where the motor is used for improving the power factor of the supply source a power factor meter (with current transformers in the line circuit) is convenient and desirable as an aid to proper adjustment of the motor field and as a direct indication of the line power factor.

Field switches may be supplied when the purchaser has specified them or where the motor is excited from a source external to the motor generator. They are ordinarily not required or supplied with standard motor generators.

The following additional comments apply specifically to the indicated diagrams.

Fig. 37. The Type Q starter shown is equally adaptable for three-phase motors, whether two single-phase or one three-phase auto-transformer is used for starting. A slight modification in direct-current starting connections is sometimes employed as follows: A single-pole single-throw series-field short-circuiting switch is supplied at the generator and the upper jaw of the starting switch is connected to the negative generator lead. This replaces the starting lead between the resistance and the equalizer terminal on the generator. The two-pole double-throw switch shown for the low voltage coil circuit of the direct-current breaker is necessary only where the set may be started from either the alternating-current or the direct-current sides.

Fig. 38. Heavy current two-phase circuit-breaker starters are made up of a four-pole single-throw running breaker interlocked with two three-pole single-throw breakers operated in tandem from the starting handle. Heavy capacity three-wire direct-current generators either have four-pole circuit-breakers with reduced capacity inner equalizer poles at the switchboard and connected as in this diagram or an electrically-operated two-pole breaker mounted at the generator and connected in the armature leads. The two-pole breaker may be mounted on the switchboard but the two additional main leads required between the switchboard and the generator for this arrangement is a large item in cost especially for large machines. Reverse current protection is not indicated as the motor voltage would not hold up in case of alternating-current power interruption, as in the case of a synchronous motor, and the alternating-current breaker will trip on low voltage, and with it the direct-current breaker.

Fig. 39. With generators in parallel, starting is sometimes done from the equalizer bus-bars. The lower stud of the starting switch is then connected to the equalizer switch, the positive switches are furnished single pole and the extra single throw switch in the negative is omitted.

Fig. 40. The negative and equalizer switches are often omitted when the installation has but one generator. With a switchboard of this type a direct-current starting switch would have to be connected in shunt with the positive switch and a third single-pole single-throw switch supplied at the generator for short-circuiting the series field during starting.

If the installation consists of only one motor generator, the low tension breaker may be non-automatic and the transformer and motor considered as a unit so far as overload protection is concerned.

Fig. 41. The negative circuit-breaker is recommended for high voltage direct-current machines due to the increased tendency for flash overs and insulation failures but it is supplied only when purchasers specify this protection.

Fig. 42. This general arrangement is adaptable for a station having several duplicate heavy capacity motor generators. Spare starting and exciting apparatus is necessary so that their failure will not tie up the station.

Fig. 43 and 44. The field reversing switch is furnished for the generator or for the motor, according to which machine's field reversal will more readily bring the two frequency changers into correct phase relation. Automatic generator voltage regulation may be had where the frequency changer set has two exciters.

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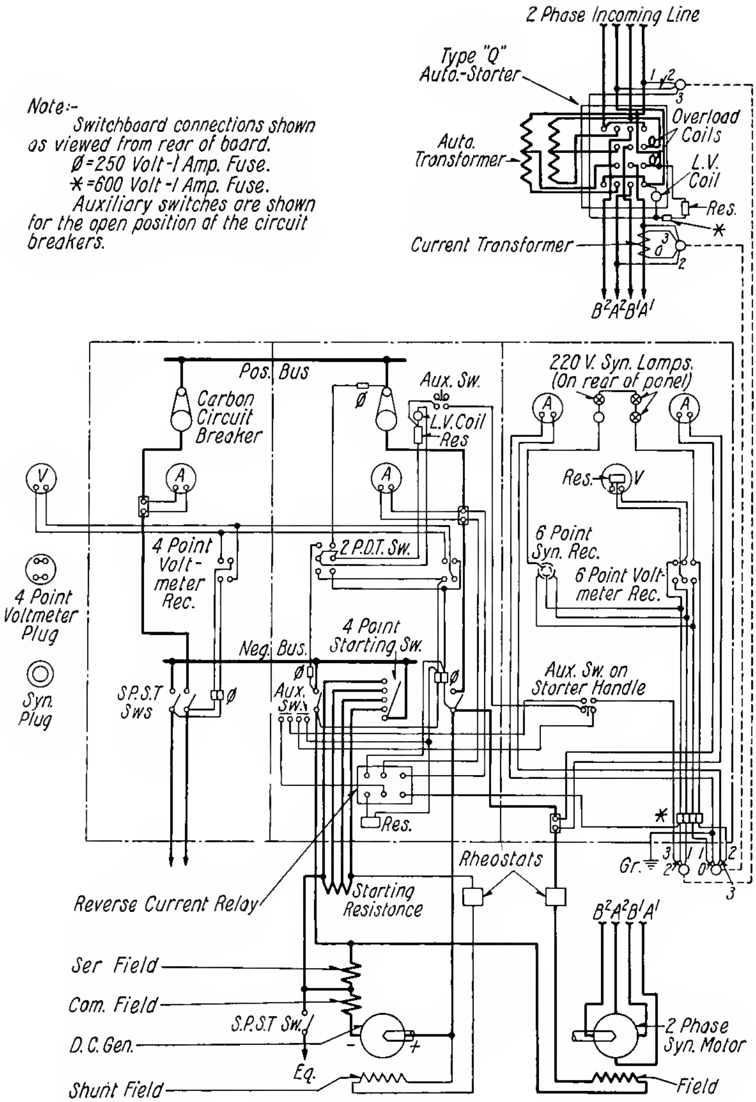


Note:-
Switchboard connections shown as viewed from rear of board.
Ø=250 Volt-1 Amp. Fuse.
*=600 Volt-1 Amp. Fuse.
Auxiliary switches are shown for the open position of the circuit breakers.

FIG. 37—440-VOLT, 2-PHASE INCOMING LINE AND 440-VOLT, 2-PHASE, SELF-STARTING SYNCHRONOUS MOTOR DRIVING A 250-VOLT 2-WIRE D.C. GENERATOR AND ARRANGED FOR STARTING EITHER FROM THE D.C. END OR FROM THE A.C. END BY MEANS OF TWO SINGLE-PHASE-AUTO-TRANSFORMERS. THE MOTOR IS EXCITED FROM THE D.C. GENERATOR

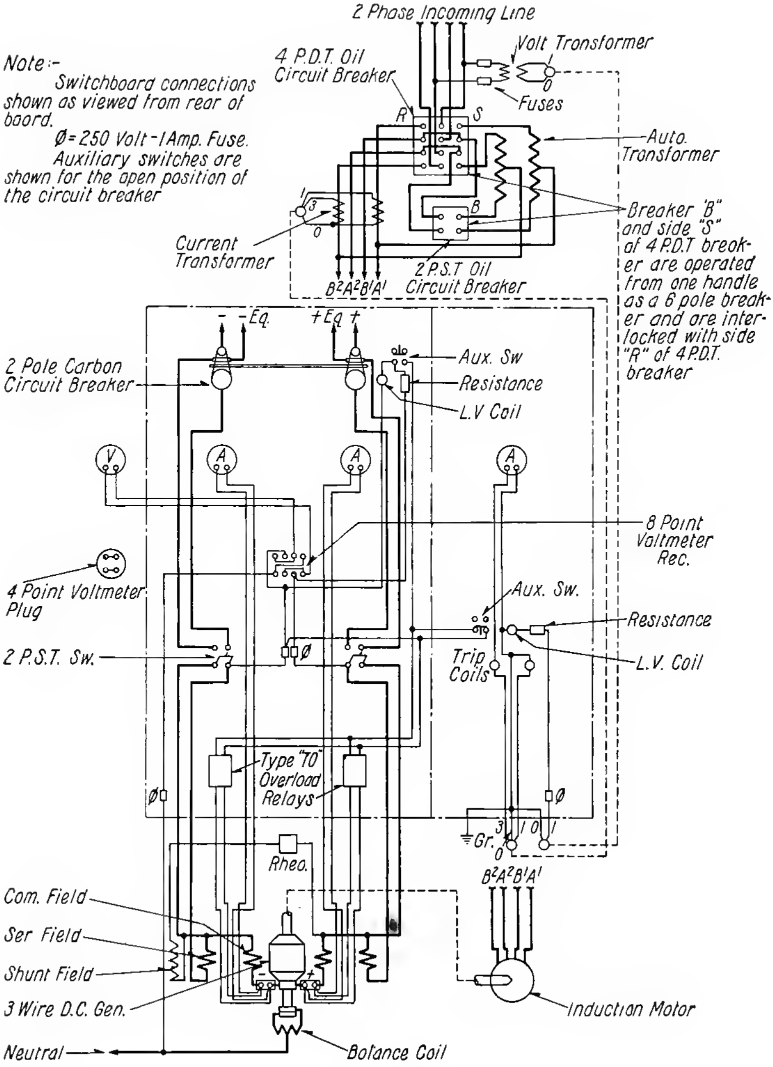
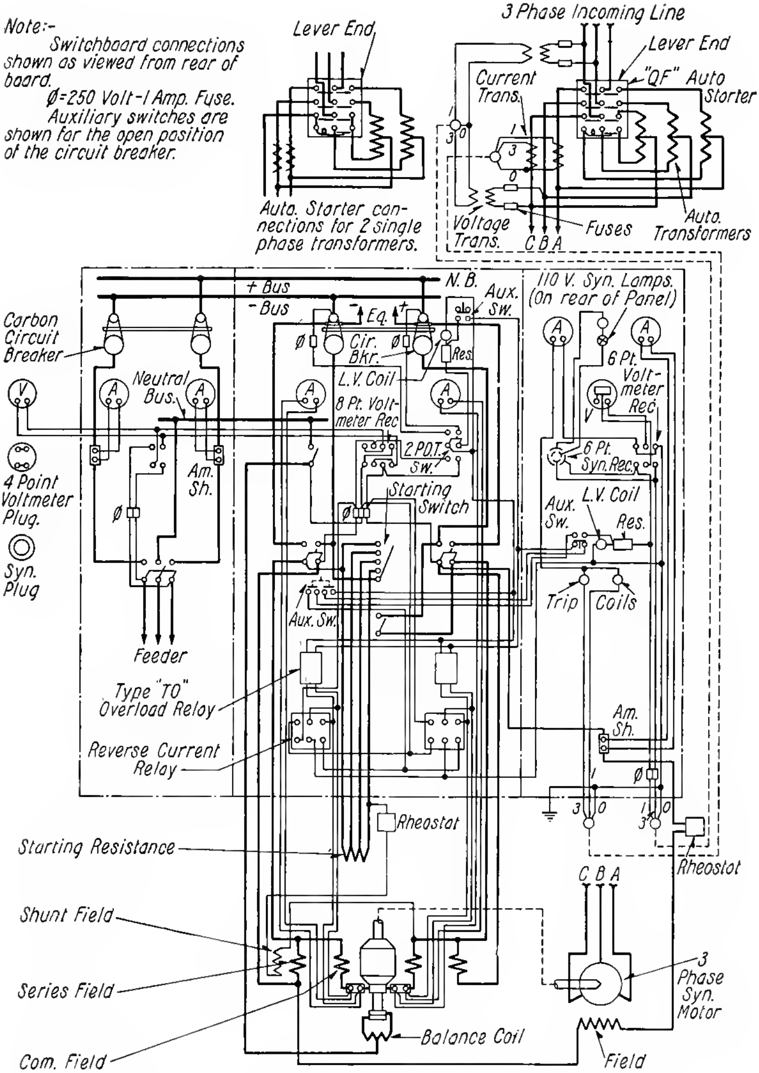
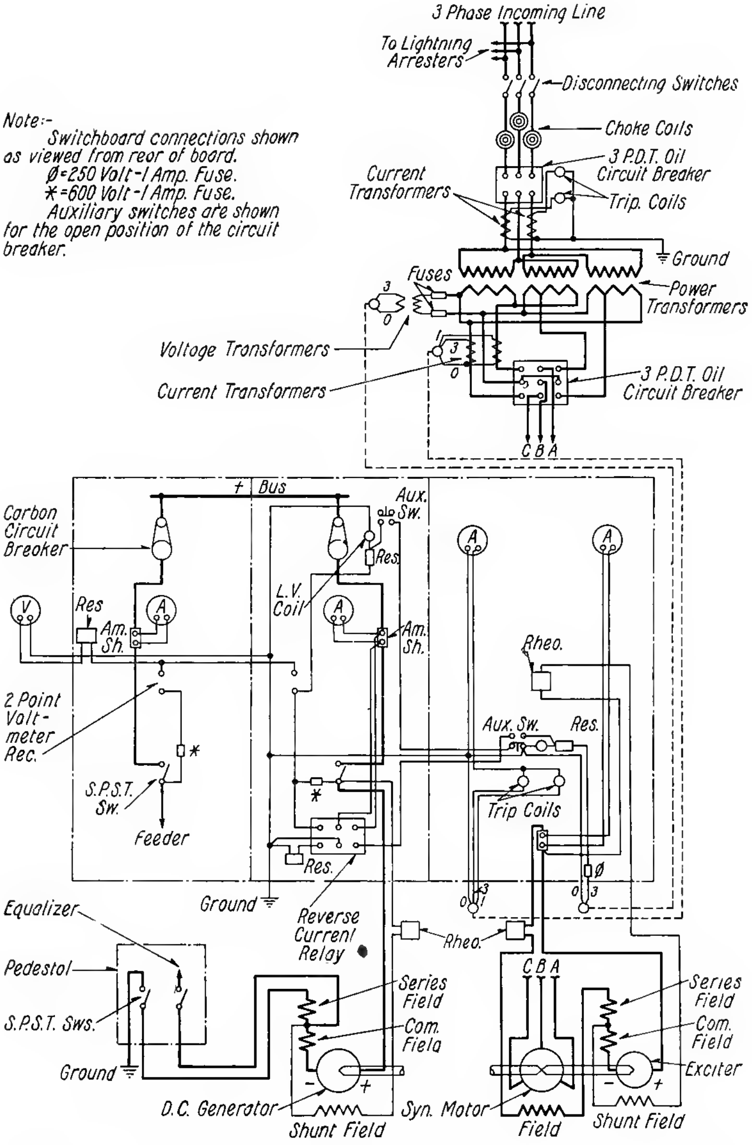

2 Phase Incoming Line
Note:-
Switchboard connections shown as viewed from rear of board.
0=250 Volt-1Amp. Fuse.
Auxiliary switches are shown for the open position of the circuit breaker
4 P.D.T. Oil Circuit Breaker
Volt Transformer
Fuses
R
S
1
0
Auto. Transformer
Breaker "B" and side "S" of 4 P.D.T break-er are operated from one handle as a 6 pole break-er and are inter-locked with side "R" of 4 P.D.T. breaker
B
1
3
0
Current Transformer
$B^2A^2B^1A^1$
2 P.S.T Oil Circuit Breaker
- -Eq.
+Eq +
2 Pole Carbon Circuit Breaker
Aux. Sw
Resistance
L.V Coil
V
A
A
A
8 Point Voltmeter Rec.
4 Point Voltmeter Plug
Aux. Sw.
Resistance
2 P.S.T. Sw.
0
Trip Coils
L.V. Coil
Type "70" Overload Relays
0
0
3
1 0 1
Gr.
0
$B^2A^2B^1A^1$
Rheo.
Com. Field
Ser Field
Shunt Field
3 Wire D.C. Gen.
-
+
Neutral
Balance Coil
Induction Motor

FIG. 38—2200-VOLT, 2-PHASE, INCOMING LINE, 2200-VOLT, 2-PHASE, SELF-STARTING INDUCTION MOTOR DRIVING A 250-VOLT, THREE-WIRE D.C. GENERATOR. ARRANGED FOR STARTING FROM A.C. END BY MEANS OF TWO SINGLE-PHASE AUTO-TRANSFORMERS



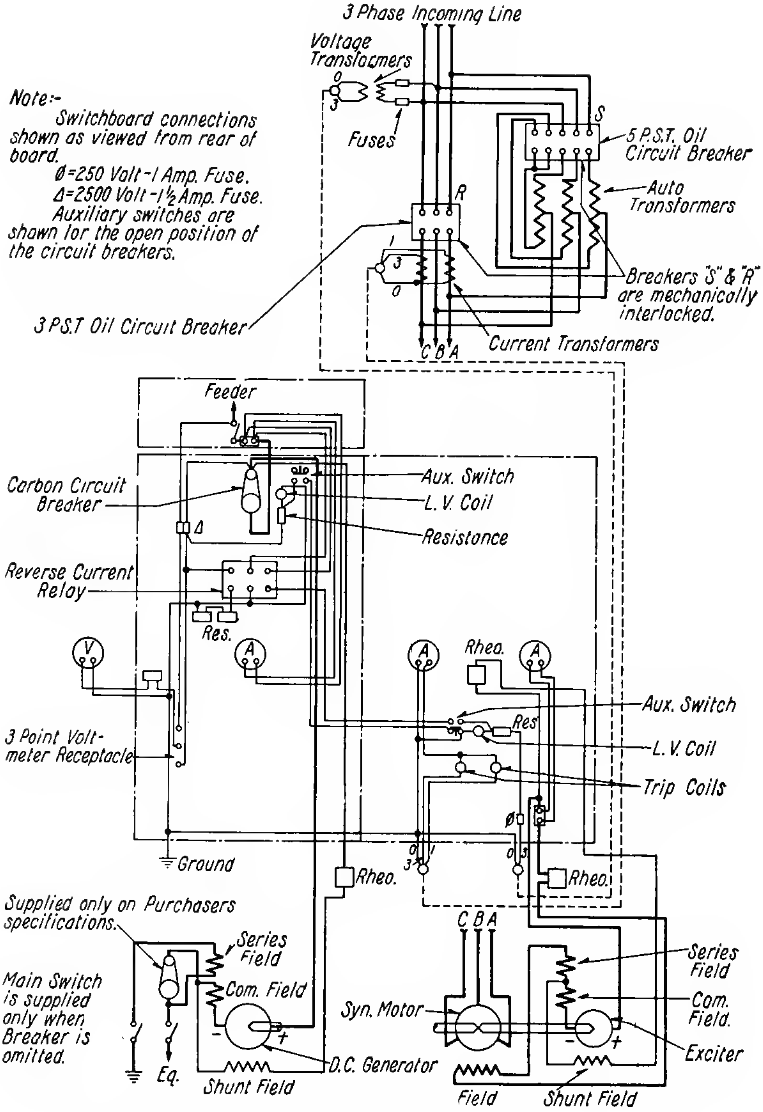
Note:-
Switchboard connections shown as viewed from rear of board.
Ø=250 Volt-1 Amp. Fuse.
Auxiliary switches are shown for the open position of the circuit breaker.

FIG. 39—6600-VOLT, 3-PHASE, INCOMING LINE, AND 6600-VOLT, 3-PHASE, SELF-STARTING SYNCHRONOUS MOTOR DRIVING A 250-VOLT, 3-WIRE D.C. GENERATOR. ARRANGED FOR STARTING FROM EITHER D.C. END OR A.C. END BY MEANS OF TWO SINGLE-PHASE OR ONE THREE-PHASE AUTO-TRANSFORMERS. MOTOR IS EXCITED FROM D.C. GENERATOR.



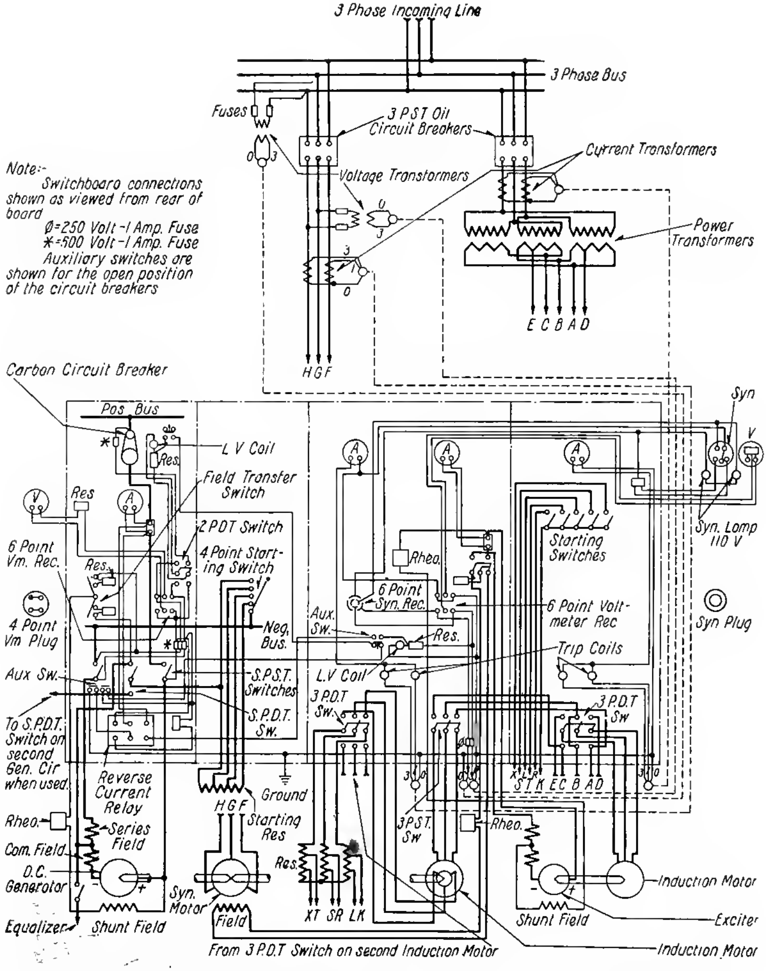
Note:-
Switchboard connections shown as viewed from rear of board.
Ø=250 Volt-1 Amp. Fuse.
✱=600 Volt-1 Amp. Fuse.
Auxiliary switches are shown for the open position of the circuit breaker.

FIG. 40—3-PHASE, INCOMING LINE WITH UNGROUNDED NEUTRAL, AND 2200-VOLT, 3-PHASE SELF-STARTING, SYNCHRONOUS MOTOR DRIVING A 600-VOLT, TWO-WIRE, D.C. RAILWAY GENERATOR, ARRANGED FOR STARTING FROM A.C. END BY MEANS OF STARTING TAPS ON A STEP-DOWN TRANSFORMER



Note:-
Switchboard connections shown as viewed from rear of board.
Ø=250 Volt-1 Amp. Fuse.
Δ=2500 Volt-1½ Amp. Fuse.
Auxiliary switches are shown for the open position of the circuit breakers.

Fig. 41—13200-Volt, 3-Phase, 60-Cycle, A.C. Self-Starting Synchronous Motor Driving a 1500-Volt, D.C. Railway Generator. Arranged for Starting From A.C. End by Means of a 3-Phase Auto-Transformer



Note:- Switchboard connections shown as viewed from rear of board
Ø=250 Volt-1 Amp. Fuse
*=500 Volt-1 Amp. Fuse
Auxiliary switches are shown for the open position of the circuit breakers

FIG. 42—6600-VOLT, 3-PHASE INCOMING LINE AND 6600-VOLT, 3-PHASE SYNCHRONOUS MOTOR DRIVING A 600-VOLT, 2-WIRE D.C. GENERATOR. ARRANGED FOR GROUP STARTING FROM EITHER D.C. END OR A.C. END BY MEANS OF A WOUND ROTOR INDUCTION MOTOR THROUGH STEP-DOWN TRANSFORMERS

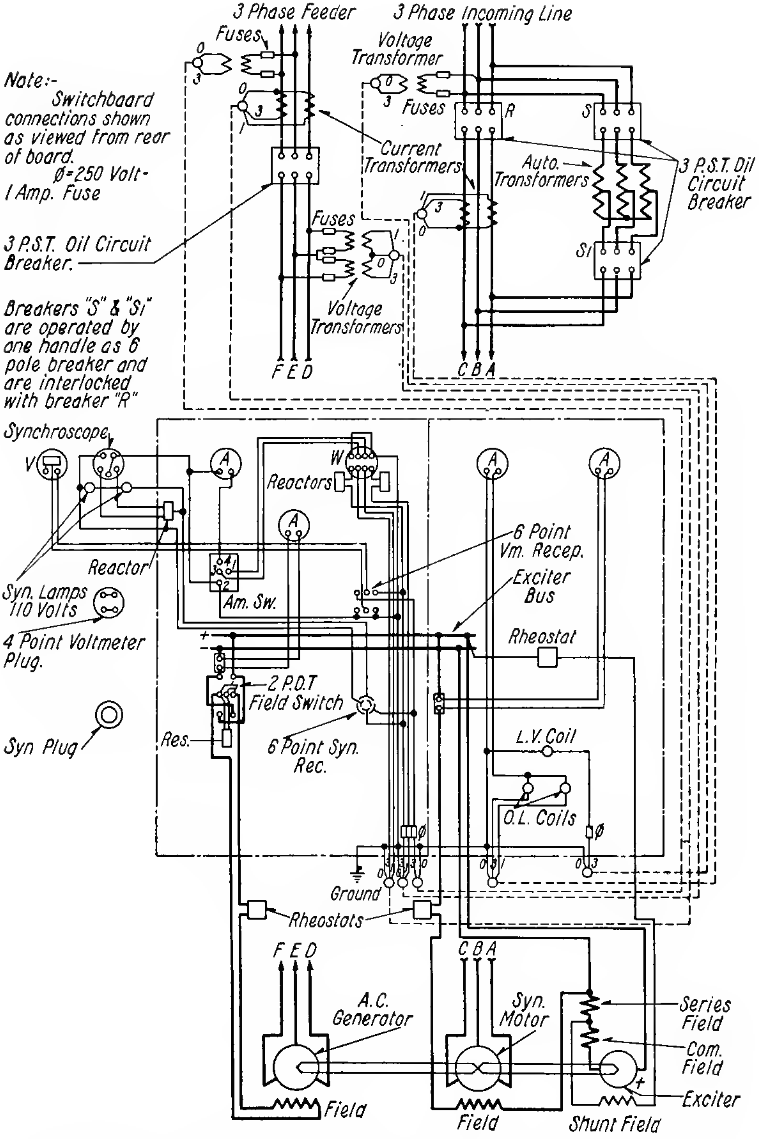


Fig. 43—6600-Volt, 3-Phase Incoming Line and 6600-Volt, 3-Phase, 25-Cycle Self-Starting Synchronous Motor Driving a 2400-Volt, 3-Phase, $62\frac{1}{2}$-Cycle A.C. Generator. Arrange for Starting by Means of 3-Phase Auto-Transformer. Motor and Generator Have a Common Exciter

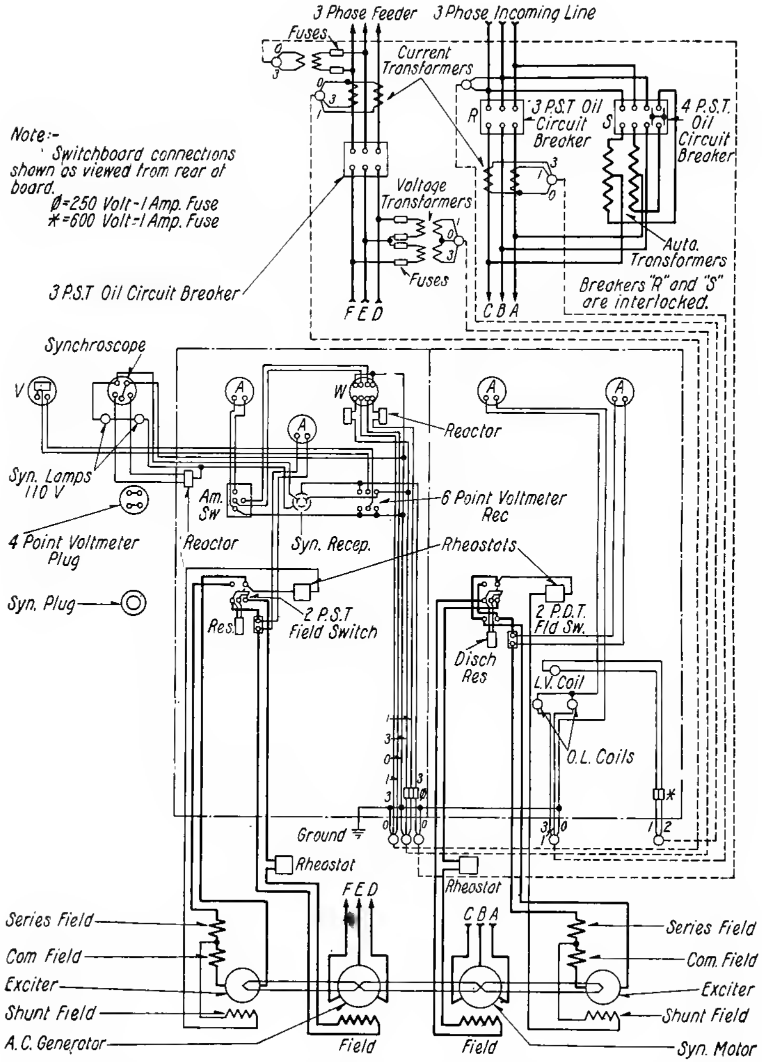


FIG. 44—440-VOLT, 3-PHASE INCOMING LINE AND 440-VOLT, 3-PHASE, 25-CYCLE SELF-STARTING SYNCHRONOUS MOTOR, DRIVING A 2400-VOLT, 3-PHASE, 60-CYCLE A.C. GENERATOR. ARRANGED FOR STARTING BY MEANS OF TWO SINGLE-PHASE AUTO-TRANSFORMERS. MOTOR AND GENERATOR HAVE INDIVIDUAL EXCITERS

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